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Journal
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The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 240 DECEMBER, 1945 No. 6

HYPERSENSITIZING AND LATENSIFICATION: A PRELIMINARY SURVEY.

BY

S. E. SHEPPARD, W. VANSELOW AND R. F. QUIRK.

Communication No. 1051 from the Kodak Research Laboratories.

There are two subjects of perennial interest to seriously-minded photographers. One consists in attempting to improve the sensitive material furnished by photographic manufacturers, by processes generally termed "hypersensitizing," the other amounts to attempts at rectifying the consequences of inadequate exposure to light of said material—or of such material lacking sufficient sensitivity for the available light. These latter attempts to resuscitate the moribund or permaturely dead may be left until development or thereafter, or may be interpolated, as "intensification of the latent image," in the period between exposure and development.

It is the comparison of hypersensitizing with this last category that we are mainly concerned. The title is one applied by the DuPont Film Manufacturing Corporation [1] to post-exposure flashing, at low intensity levels,* of high-speed films. It was extended, we believe by Dr. Berg of the Research Laboratory of Kodak Limited, to cover what had been previously termed "intensification of the latent image" [2,3] but which might be better entitled "extension of the latent image," since it pretends to demonstrate the existence (and final viability) of sub-latent image steps or thresholds more or less considerably below the threshold for normal development, as well as an increase of *mass* of the recognized latent image, *qua* developable density at higher exposure levels. The supposed general phenomenon can be illustrated by the diagram (Fig. 1). In this figure the lower graph represents, for a given emulsion, the D-log E or D-log $I(t)$ curve at ultimate useful development, and the upper graph, the curve obtainable, for identical development, of the same

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* Recommended was "25 to 40 minutes' exposure to a dark green safelight."

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

material, identically exposed, but subjected to an intermediate (post-exposure, pre-development) "latensification" process. We admit the presence here of some question-begging adjectives, to wit, "ultimate," "useful," and "identical." Actually, it will be seen that the second, in so far as it signifies a normal degree of scientific reproducibility, disposes of the need for complete specification of the first. It has been claimed that this phenomenon can be produced by various methods which are now summarized and, in some degree, classified or typed. The results of some of these methods are shown in Fig. 2.

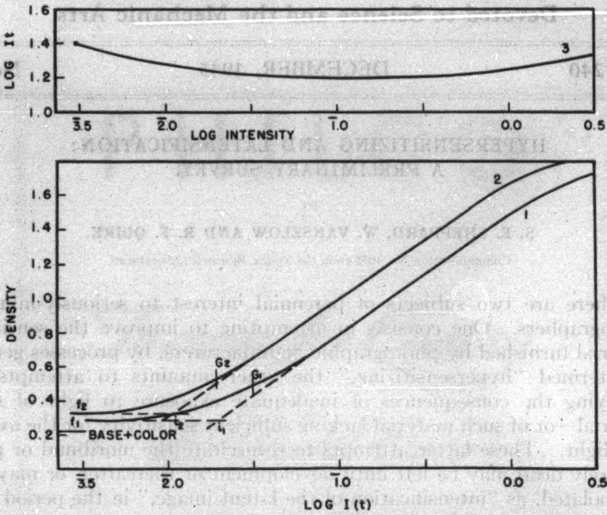

Fig. 1. Arbitrary sensitometric curves of an untreated sample 1, and a latensified sample 2, indicating inertia speeds, i_1 and i_2; and gradient speeds at G_1 and G_2 at a density 0.2 above fog levels, f_1 and f_2. Curve 3, assumed reciprocity failure curve.

We should notice that certain authors have described what is here termed "latensification" as a variety of "hypersensitizing." Although the effects *may* be the same, we consider this terminology confusing, and would restrict "hypersensitizing" * to procedures antecedent to the image-forming (or differential) exposure to light. Thus, a "flash" or "all-over" exposure to light (of any intensity level, or duration, and

---

* The term "hypersensitization" has been at various times and by various authors † *as* limited to after-increase of the sensitivity to longer wavelengths conferred by dyes. However, we are using it for any effective spectrally non-selective, increase of sensitivity produced after emulsion-coating and prior to exposure to light for image-making.

† (*Cf.* Carroll and Hubbard, *loc. cit.*)

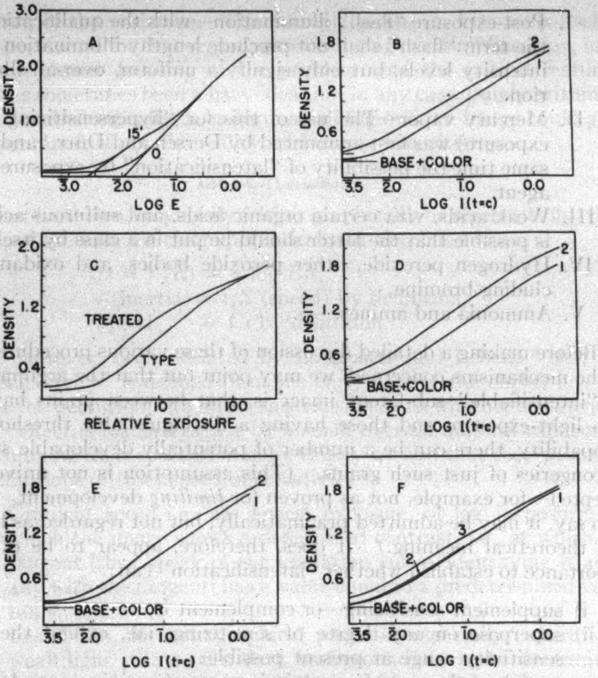

FIG. 2. **Latensification agents.**

A. Fogging exposure of 0 and 15 minutes to constant low intensity light source. HP.2 Panchromatic Leica film. Reproduced from G. S. Moore, *Phot. J.*, 81, 28 (1941).

B. Motion Picture Panchromatic Negative Emulsion V. 1. untreated; 2. treated with mercury vapor.

C. Ansco Triple S Pan, intensified by bathing for 10 minutes in carbon tetrachloride containing 1 per cent. of 50–50 formic-acetic acids. Reproduced from F. W. H. Mueller and J. E. Bates, *J. Phot. Soc. Amer.*, November 1944, p. 589.

D. Motion Picture Panchromatic Negative Emulsion V. 1. untreated; 2. treated with ammonia.

E. Motion Picture Panchromatic Negative Emulsion VI. 1. untreated; 2. treated with sulfur dioxide.

F. Motion Picture Panchromatic Negative Emulsion V. 1. untreated; 2. bathed in water; 3. bathed in sulfurous acid.

of any color), made prior to the image-forming (or differential) exposure, may be "hypersensitizing," but if applied after said differential exposure (and found to produce the extension and intensification of image), it should be termed "latensification." With these preambles and provisos, we suggest the following classification of latensifying methods:

I. Post-exposure "flash" illumination—with the qualification that the term "flash" shall not preclude lengthy illumination at low intensity levels, but only signify a uniform, over-all illumination.

II. Mercury vapor—The use of this for "hypersensitizing" (pre-exposure) was first announced by Dersch and Dürr [4] and at the same time the possibility of "latensification" by exposure to this agent.

III. Weak acids, viz., certain organic acids, and sulfurous acid. It is possible that the latter should be put in a class by itself.

IV. Hydrogen peroxide, other peroxide bodies, and oxidants, including bromine.

V. Ammonia and amines.

Before making a detailed discussion of these various procedures, and of the mechanisms concerned, we may point out that the argument for an "intensifiable" sub-latent image is, that between grains having a zero light-exposure and those having a distinguishable threshold developability, there can be a number of potentially developable steps—as congeries of just such grains. (This assumption is not universally accepted—for example, not as proven for *limiting* development. That is to say, it may be admitted pragmatically, but not regarded as having any theoretical meaning.) It does, therefore, appear to be of some importance to establish whether "latensification" can:

i) supplement sensitizing—or complement it,
ii) superpose on any degree of sensitizing, i.e., extend the total sensitivity range at present possible:
    (a) at the cost of a certain increase of graininess, or decrease of resolving power,
    (b) without such image deterioration,
iii) be shown to be a real, not a factitious phenomenon, capable of giving further information on the formation of the latent image, and on emulsion sensitivity.

In this connection it is evidently desirable to ascertain its relation to Reciprocity Law Failure; is it, *latensification*, more evident for the toe region of underexposure for low intensity than for the same (energetically) underexposure region for high-intensity illumination?

Finally, it may become possible to answer the query as to whether "latensification" can do more than can be achieved by full sensitization of emulsions of the same grain size-distribution, coating thickness, and so forth.

DEFINITIONS AND PONDERABILIA.

Assertions concerning latensification have frequently been made without adequate definition of the premises, and without adequate separation of the variables. The example given—in Fig. 1—is itself a case in point, and for that reason, as attempting oversimplification, may help to a clearer focusing of the problem, and the critical features. There has sometimes been a hazy idea that in any case, purely arithmetically or mathematically, a uniform small fog over an image could give the appearance, if not the reality, of increased sensitivity.

Arithmetical Latensification.

It can be shown very easily, either graphically or algebraically, that this is not the case for the hypothetical and simplified issue:

$$D = f(E) = \gamma \log E/i,$$
$$i \text{ (inertia)} = 1/S \text{ (speed) by definition,}$$
$$\text{Speed} = 1/i \text{ by definition.}$$

It has, however, been declared by Labussière and Lebelle [5] that the way "sensitivity" is defined from the early part of the curve, i.e., the form of the definition, can affect the decision as to whether a "latensification" effect is reached or not by a small over-all uniform exposure ϵ.

Examining their contention more closely we find that they postulate two definitions of (toe) speed or sensitivity:

A. Gradient speed, i.e., the lowest exposure, or log (exposure), at which the image shows a determined contrast, i.e., at which the tangent [they speak of the gradation curve, identifying it actually with the tangent] has a value equal to a predetermined value $\tan \theta$.

B. Less often, for astrographical purposes especially, where very weak light points on a dark background are to be determined, without regard to contrast, the sensitivity is better expressed by the threshold value (Schwellenwert).

These writers assume that the Reciprocity Law holds at least in a restricted region (for their argument, and it appears later, for their experiments), so that the photographic action of two *successive* exposure ϵ and E is the same as that of a single continuous exposure $\epsilon + E$.

In any general and full consideration of the problem it is certain, of course, that the assumption cannot be made; indeed the most important possibilities of "latensification" are in the regions of reciprocity failure, particularly, it is probable, in that of low-intensity failure.

Since reciprocity failure for intensity x time has been shown to be essentially responsible for, or identical with, intermittency failure, Labussière and Lebelle's definition will pass for the required small region. Their argument is that, in Case B, when sensitivity is defined as *gradient speed*,

$$\frac{\Delta D}{\Delta \log E} = \lambda_0,$$

then it will depend upon the shape of the characteristic curve whether a post-exposure (or for that matter, a pre-exposure, so far as mere definitions are concerned) will give an (apparent) sensitivity increment. Similar conclusions are obtained for the "Schwellenwert," although this is by nature less susceptible to definition and measurement. These writers, from examination of a number of emulsions, found in most cases no effect of post-exposure, but in a few cases a small increase by pre-exposure in wedge-threshold sensitivity.

Considerations of the proportion of (assumedly) *unexposed* to exposed (ex hypothesi) grains in different parts of the image[6] have led to the conclusion that the sensitometric subtraction of an equal "fog" reading from all densities must lead to error.

Generally, the absolute magnitude of the error will be the less, the lower the exposure and the resultant density. An early approximation reducing the relative error was to assume that the "fog" correction should be proportional to the non-exposed silver halide.[6] It is evident that this type of correction is even more applicable to the case of latensification than to sensitometry of normal exposure.*

I. LATENSIFICATION BY POST-EXPOSURE FLASH ILLUMINATION.

The relatively small amount of quantitative date on this procedure only goes so far as to indicate that (i) little difference is to be observed between the effects of equal pre- and post-exposure flash illumination; (ii) both treatments are principally effective in the regions of low intensity.

Both procedures are historically as old as photography itself.[7]

In connection with both the theory and the occasionally suggested practical application of such procedures, a remark of Eder's is still very much to the point:

"It is perhaps not superfluous to remark that in view of the noteworthy sensitivity of gelatino-silver bromide it is much more difficult to hit the right degree of post-exposure than with wet collodion and avoid fog than with the latter. . . . But with less sensitive fog-free plates there is a noticeable [latensifying] † effect of post-exposure."

In further discussion of post-irradiation Eder[8] indicated his belief in an analogy between this and the action of the so-called "ripening process," i.e., of emulsion-sensitizing. "In gelatino-silver bromide plates, in all probability the same effect as that given by pre- or post-irradiation is obtainable in a purely chemical manner, without recourse to light. One must, that is to say, introduce a minimum reduction of the silver bromide. This is done by long heating in the so-called 'ripening process.' Actually, prolonged digestion in the heat [of an emulsion] † leads to fogging, while also the high sensitivity of heatripened gelatin emulsions is very harmful when they are treated with reagents which convert reduced silver bromide back to normal silver bromide."

---

* Because at higher exposures the effect of reaction products becomes greater.

† [ ] Words in brackets introduced by authors.

Eder did point out, however, that, owing to the topography of a coated emulsion, pre- or post-irradiation could not give exactly the same effect as homogeneous emulsion-sensitizing. Interest in pre- and post-irradiation for latensification has recurred sporadically since the early days, especially wherever exposures had to be made with very feeble illumination. The matter got taken up in connection with photographic theory of low-intensity R. F.,[9] principally from the point of view of Gurney and Mott's hypothesis of latent-image formation. These authors had suggested as an explanation of low-intensity R. F. a supposed tendency—purely thermal or statistical—of electrons to be ejected, from a "sensitivity speck" that has become a development center, before the electron density built up to a certain critical minimum postulated as necessary for the formation of an actual silver nucleus. This mountain of assumptions was modified by Webb and Evans.[9] The earlier stages of a *silver* nucleus they supposed to have a greater probability of thermal (thermionic) disintegration than later, larger, ones. In support of this they showed that if in a mixed total exposure, the first half [of the total energy] were at high intensity, then the second half at low intensity would be approximately as efficient in regard to *density* produced * as if the whole exposure were made at the high intensity.

Whereas many observers had concluded that post- and pre-exposure irradiations were equivalent, Moore [10] concluded that post-exposure low-intensity irradiation (at the fogging level) was definitely more effective than the same pre-irradiation. However, his technique does not appear to have allowed a very high degree of accuracy. But his conclusion that with forced development no significant increase in (camera) speed was noted for either pre- or post-exposure irradiation is interesting, as raising again the question of the existence of a true "grain" induction effect.

Comparison with *other* types of latensification, in which a purely crystallo-electronic mechanism cannot be assumed, is therefore of much interest.

II. MERCURY (VAPOR) LATENSIFICATION.

This process, and also pre-exposure "hypersensitization" by the same means, were discovered by F. Dersch and H. Dürr.[4]

A comparison of the two procedures, operated under nearly identical physical conditions, has brought out some interesting differences. It should be noted that to get reasonable precision (reproducibility) it was found necessary to condition the photographic layers to constant relative humidity, and to maintain the R. H. and the temperature constant. The conditions chiefly used were 50 per cent. R. H. and 20° C. and 75 per cent. R. H. and 24° C. Typical "hypersensitization" curves are shown in Fig. 3 for a period of 3 to 4 days. Fig. 4 and 5 illustrate other actual progressions of maximum speed, contrast, and fog, of different rates.

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* It is perhaps unfortunate that no measurements were made of the *silver* produced.

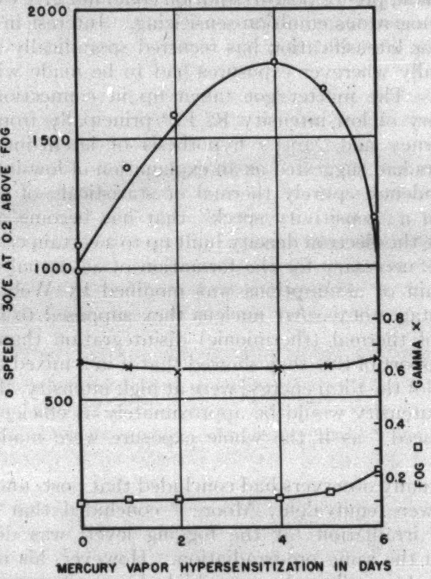

Fig. 3. Mercury vapor hypersensitization of Motion Picture Panchromatic Negative Emulsion I at 20° C. and 50 per cent. R. H.

The principal characteristics, in a broad sense, of mercury *hypersensitizing*, are (i) a more or less rapid rise to a maximum effect with time of treatment, followed by a decline, generally with increasing *fog*; (ii) a decay of the intensification when the treated material is removed from the mercury atmosphere; (iii) the possibility of repetition of the cycle, without persistent increase in fog. It has been carried through three cycles. On the other hand, in mercury *latensification*, the speed increase—toe or gradient speed—took some time *after* exposure to mercury (13 hours) to reach its highest value, e.g., there was 50 per cent. increase in 8 to 10 days at 24° C., which then became stable. (Fig. 6.) Observations at higher temperatures (50° C. and 75° C.) were found to be rendered inconclusive because of considerable changes in the control

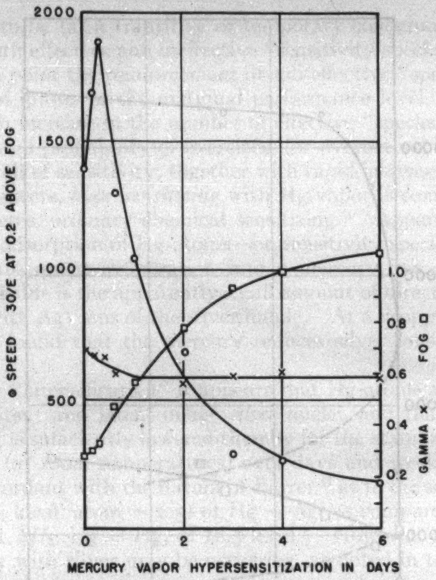

FIG. 4. Mercury vapor hypersensitization of Motion Picture Panchromatic Negative Emulsion II at 20° C. and 50 per cent. R. H.

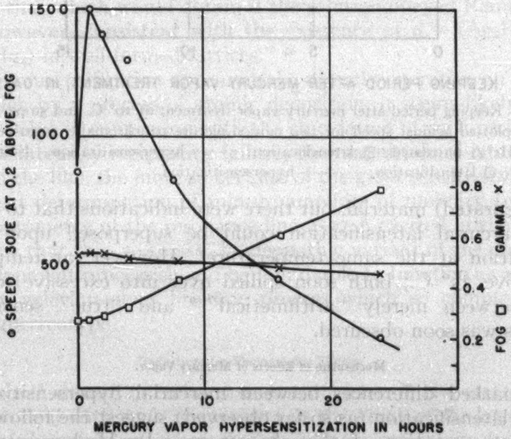

FIG. 5. Mercury vapor hypersensitization of Motion Picture Panchromatic Negative Emulsion III at 20° C. and 50 per cent. R. H.

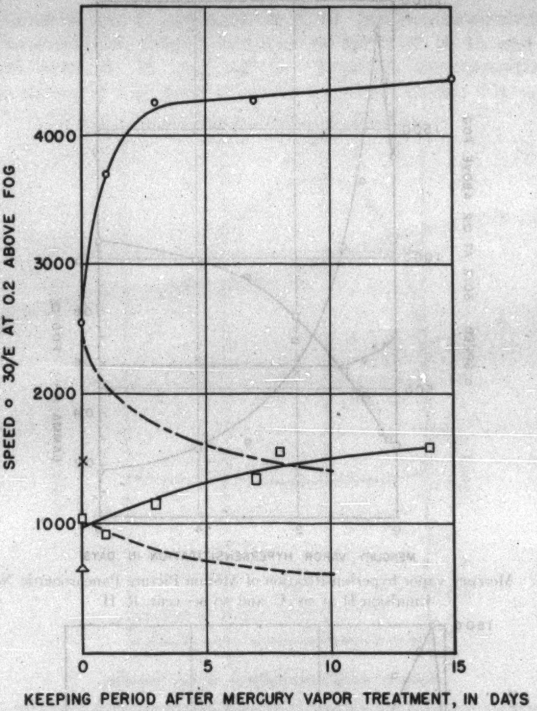

FIG. 6. Keeping period after mercury vapor treatment at 20° C. and 50 per cent. R. H. for 3 hours plotted against speed for two motion-picture panchromatic negative emulsions. Emulsion VII: △ untreated; ⊡ latensification; ---- hypersensitization. Emulsion VIII: × untreated; ⊙ latensification; —— —— hypersensitization.

(non-mercurated) material, but there were indications that to a certain degree mercurial latensification could be superposed upon thermal latensification at the same temperature. However, at temperatures much above 25° C., both soon spilled over into excessive fog. The margin between merely "arithmetical"* and "true" sensitometric differences was soon obscured.

Mechanism of Effects of Mercury Vapor.

The marked differences between mercurial hypersensitizing and mercurial latensification (as so far observed) suggest the following provisional interpretation of the phenomena. In Hg-hypersensitizing, there appears to be (a) a transitive or temporary condensation of Hg-atoms upon both effective and ineffective "sensitivity specks," whereby up to a certain point the reinforcement of sub-effective "specks" brings a proportion of grains to the marginal performance level, (b) beyond which point, an increase in the number of effective "specks" per grain, *plus* the increased probability of oversized (or overactive) specks produces a *rapid* fall of sensitivity, together with rapid increase of fog.

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* Cf. p. 443.

In these respects, *hypersensitizing* with Hg-vapor is complementary to, and completes, ordinary chemical sensitizing.[11] Apparently, there is preferential adsorption of Hg-atoms—on sensitivity specks, probably Ag_2S—with subsequent evaporation into a mercury-free atmosphere. What is remarkable is the apparently small amount of direct interaction of Hg-atoms with Ag^+ ions of the silver halide. At a dropping mercury electrode it is found that the mercury reduces silver ions to metallic silver.

In mercury "latensification" it appears that Hg-atoms are adsorbed to both sub-latent and latent-image *silver* nuclei, and that the vapor pressure of Hg is sufficiently lowered thereby for the stabilization of the reinforcement (at room temperatures) over days and weeks. (This is somewhat discordant with the datum of Barrer [12] as to the small adsorption heat (ΔH_1 k.cal./atom = 2.5) of Hg − Ag, as compared to a condensation heat ΔH_2, Hg − Hg, of 18.5 k.cal.) However, stable alloying of mercury with silver may be occurring, as noted in the following paragraph.

"The solubility of Ag in Hg at room temperature is less than one-fortieth of that which would obtain if the solution obeyed Raoult's law. This is, however, consistent with the existence of $\beta - (Ag_5Hg_4)$ and $\gamma - (Ag_5Hg_8)$ in well-formed lattices." [13]

Since Hg-latensification appears to be directly operative on the sub-image nuclei, by a process of atomic deposition, it seems likely that it may be of value in connection with the elucidation of such problems as that of low-intensity reciprocity failure, the magnitude of latent-image nuclei, and the like, the more so because of the great sensitivity possible in the direct determination of minute amounts of mercury by photoelectric photometry of the resonance line 2537 Å excited in the vapor.[14] It is curious that this, so to say, homeopathic variant of the daguerreotype development process should be found able to function as an auxiliary to the gelatino-silver bromide process which so completely displaced daguerreotype.

Deductions for Photographic Effects.

We have [15] almost an embarrassment of riches in the matter of hypotheses to deal with such phenomena as the *decay of the latent image, the decay of the sub-latent image, the low-intensity reciprocity failure, and the Herschel effect.*

Interpretations vary from chemical ones—in terms of rebromination of silver metal specks or atoms—to purely electronic ones, [9] in terms of thermal, or perhaps, infrared dissipation of electrons. It seems reasonable to round out the program by indicating the possibilities of dissipation * (diffusion) of silver atoms: an individual silver atom being regarded as a conjunction of a silver ion Ag^+ and an electron, having a certain amount of residual thermal energy, and not integrated in a metallic lattice. Such silver atoms might be regarded as *adsorbed* to a silver halide surface, but with lower (negative) energy than the normal heat of sublimation (condensation). The work of Estermann [16] gives data showing cadmium, copper, and silver "films" on glass whose heats of sublimation (3 to 5 k.cal.) are only 1/5 to 1/7 that of bulk metal. We may compare the value ΔH_1 for the heat of condensation in uniform layers on a foreign substrate and ΔH_2 for the heat of condensation of metal on itself:

TABLE I.

	System	ΔH_1 k.cal./atom	ΔH_2 k.cal./atom
Estermann	Cd – Ag	5.0	28.0
	Hg – Ag	2.5	18.5

A rough proportionate transfer to the case of silver would yield figures of the order:

	ΔH_1	ΔH_2
Ag – AgBr	10 – 12	65 k.cal./atom

On the other hand, H. Schmidt [17] has calculated, from rather doubtful data of Luther [17] on redox potentials of photohalides, the following:

		ΔH_1	ΔH_2
Ag on	AgCl	33 k.cal.	
	AgBr	22	65 k.cal./atom
	AgI	11.5	

It is apparent that devolution or regression of a potential latent-image center—sub-nucleus or "germ," to use Dr. Berg's notation—might be ascribed, with rather similar mathematical consequences † to one (or more!) of several processes, e.g.,

i. Thermo-electric dissipation of electrons at a sensitivity speck.
ii. Thermal diffusion of Ag^+ ions (presuming partial or total dissipation of previous negative charge).
iii. Thermal diffusion of silver atoms, not aggregated in a silver lattice.

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* Used in the sense of antithesis to concentration.

† Functionally similar, as forms of a diffusion process, but differing in absolute magnitudes of the rate constants.

iv. Thermal diffusion of some "overactive" reductor (as, for example, monothionate for sulfurous acid and bromine resulting from the primary photochemical change.)

Neither on the basis of known experimental data nor on that of these and present conceptual mechanisms, does there seem to be any reason to suppose that any process of decay of "sub-latent" image would differ specifically from a similar process for admitted "latent" image.

Schmidt makes an interesting statement relative to silver iodide: "The second possible secondary process consists therein that the adsorbed halogen atoms subsequently combine to molecules. The energy to be obtained from this process of molecule formation * is only sufficient to eliminate the adsorption combination of these atoms to silver halide in the case of the chloride and bromide. It is not enough in the case of the iodide, that is, the iodine *atoms* cannot combine to molecules. The peculiar and deviating photochemistry of silver iodide is thereby explained."

We believe that the actual values for the atomic adsorption energies obtained from Luther's data are considerably too high, but the relative values may be in order, and in this respect agree with certain other characteristics of the three silver halides, as will be noted elsewhere.

II. LATENSIFICATION BY WEAK ACIDS, INCLUDING SULFUROUS ACID.

An intensifying action of sulfur dioxide (sulfurous acid anhydride) was patented in June, 1943, by N. L. Simmons of the Eastman Kodak Company (U. S. Patent 2,368,267).

A "new method for intensifying the latent image" was announced by F. W. H. Mueller and J. E. Bates [18] in November, 1944, namely, by submitting exposed silver halide layers to the vapors of a number of organic acids, such as formic, acetic and propionic acids, also to sulfur dioxide (sulfurous acid anhydride). It is stated that in place of the organic acid vapors there may be used solutions of these in non-polar organic liquids, such as carbon tetrachloride or benzene.

In addition to those noticed, we have observed that *oxalic* acid, but not succinic, in aqueous solution, can exercise a latensifying effect.

However, our principal experience with this type of latensification has been with sulfurous acid, with which increase of the toe or gradient-speeds of high- and medium-speed emulsions by 100 to 200 per cent, was found possible, at the intensity-level of a 500-watt *tungsten lamp*, filtered to sunlight, at 75 cm.

Mechanism of Acidic Latensification.

This behavior of acids seems surprising in view of the well-known antisensitizing effect of acids, or generally, of lowered pH, in emulsion preparation, and in pre-exposure treatment.[19] It has been observed already, however, that pronounced *latensification* has been obtained by post-exposure treatment with dilute silver nitrate solutions,[3] and Sheppard and Graham [20] have called attention to the rapid fogging produced by lowering the pAg of gelatino-silver bromide emulsions below pAg = 5, and the pH below the isoelectric point of lime-processed gelatin, ca. pH $\sim$ 5.0. It is, therefore, reasonably probable that this *acid latensification* is due to *mobilization* of silver ions on the grain surface by reason of neutralizing amino-bonds or imido-bonds of gelatin which were otherwise immobilizing them.

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* Which must be only the *balance* of the usual heat of dissociation less the heat of adsorption.

This conception, of latensification by grain-surface mobilization of free Ag^+ ions, definitely relates this form of latensification to Carroll and Hubbard's [21] explanation of "hypersensitizing" by washing or by treatment with ammonia, with, however, an extended conception of the possible mechanisms of effective reduction of pAg.

The conception involves a certain reciprocity of pAg and pH for latensification (i.e., that certain acids under some conditions, may be equivalent to silver ion increments) but *not* for sensitization.

We assume that under these conditions the concentration effect of a sub-latent image speck—whether an electrostatic potential as supposed by Gurney and Mott or other—is boosted to a useful level. It may be that the Ag^+ ions thus concentrated are neutralized *before* development, or that there is only a local superconcentration, with or without further "activation" by adsorption to the sub-speck.

If neutralization be assumed to occur prior to any action of the developer, there still remain the possibilities of the silver atoms:

i. remaining isolated—but adsorbed,
ii. diffusing away from the center,
iii. aggregating to a crystal nucleus.

The nature of the *developable latent image*, in respect of the just-mentioned states, is still largely unknown. It is possible that in its first appearance—and eventually thereafter—the latent image as locally resultant from the absorption of quite few quanta (of optical magnitude) per unit area of, say, 10 Å^2— consists of "filmy" rather than of three-dimensional crystalline silver, and that such surface film aggregates may be composed of "twins," and, therefore, the first nuclei are diatomic aggregates.[22] The "binding energies" in the growth of crystal nuclei from atomic metals have been discussed in terms of quantum mechanics by J. C. Slater [23] and by Taylor, Eyring and Sherman.[24] Although this was actually carried out only for Na and Cu (and H_2), certain general conclusions were reached of interest for the metal Ag. It is true that the data presented refer to the "manner in which a unit cell would grow from the vapor phase away from surfaces," whereas our ideal problem would have two differing prospects, viz., how a unit cell should grow (i) from silver atoms resulting from a silver halide lattice adjacent to an aqueous solution, and (ii) from an ionic silver solution adjacent to a silver, etc. But these are certainly only minor auxiliary complications of the same primary problem envisaged by Taylor, Eyring and Sherman. (How little removed, in a sense, is the essential photographic problem from fundamental elementary chemical quantics* can be seen by reflecting upon the actual operating conditions in daguerreotype, to wit, a polished metal bloc (of silver), a surface film of silver halide—and a developer, amplifier, or multiplier, of Hg atoms.)

An important generic result of these authors is the existence of definite steps by which the stabilities i.e., negative potential energy gains, of early configurations of a few atoms differ from each other; thus, a configuration of four atoms is more stable than that of two sodium molecules (twins) by about 2 kilocals. Here the size of the aggregates, in ultimate *number* of atoms, is the same. Several other of the more pertinent results will be dealt with elsewhere † but perhaps one should be mentioned here. "One must conclude that, until one reaches structures more complex than the unit cell, the aggregates differ energetically but little from the 'twins' visualized by Frenkel [22] as the units of deposited films of the metals, and, statistically, the twin structures would be favored."

In relation to the possibility of silver *atoms* diffusing away from a center—which could constitute a regression or decay of latent or of sublatent image—some particular results with latensification by sulfurous acid are of interest.

In Fig. 7 are shown the results of a time-series of comparisons of the change of speed after exposure to light, on development *without* and *with* a latensification treatment.

In Fig. 8 summary comparison is made. The apparent tendency to a steady *growth* of latent image after a preliminary dip will not be discussed here; it is the preliminary "decay" epoch we wish to notice. It is possible that this may be decisive, either in differentiating the mechanism of SO_2 latensification from that of other acids, and, indeed, of all other agents, or in drawing attention to a general property of sublatent image.

Special Mechanisms of SO_2 Latensification.

While it is possible, and possibly correct, to assign the action of sulfurous acid to the same mechanism as that of the organic acids, the possibility of a different, quite specific one must not be ignored. One that was first considered was that of disinterment of sub-surface nuclei (Keimbloss-legung of Lüppo-Cramer) by the solvent action of sulfite. This we feel to be excluded by the fact that it is essentially the acid

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* Understanding thereby interactions of not more than two or three bodies.

† With R. H. Lambert, in connection with thermochemical aspects of photographic development.

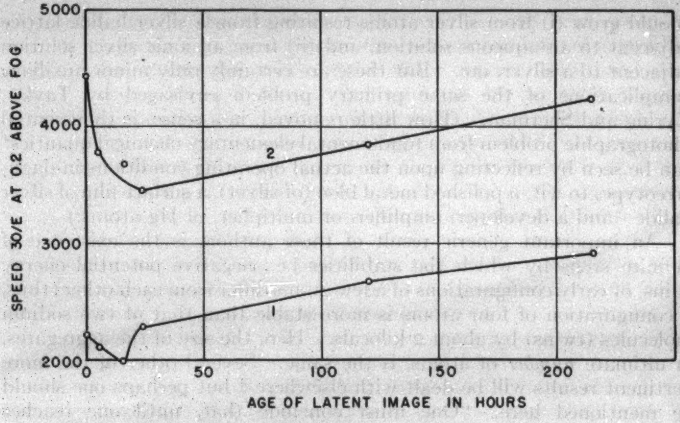

Fig. 7. Keeping of latent image previous to treatment: 1. bathed in water; 2. bathed in sulfurous acid.

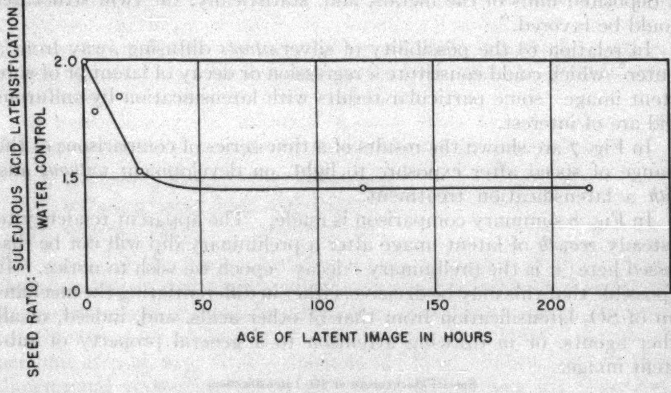

Fig. 8. Ratio of speeds shown in Fig. 7 for each keeping period of the latent image.

($SO_2 \sim H_2SO_3 \sim HSO_3^-$) which is responsible, and *not* the $SO_3^{=}$ ion. In this connection we have found experimentally that the solubility of silver bromide in sulfite solutions falls rapidly on lowering the pH, as would be expected by displacement of the equilibrium:

$$\overset{-}{\mathrm{SO}_3} + \overset{+}{\mathrm{H}} \rightleftharpoons \overset{-}{\mathrm{HSO}_3} + \overset{+}{\mathrm{H}} \rightleftharpoons \mathrm{SO}_2 + \mathrm{H}_2\mathrm{O}.$$

Thus as shown in Fig. 9 the solubility at pH 7 is *ca.* 14 times that at

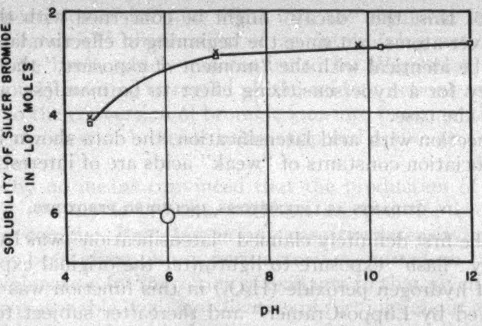

FIG. 9. Solubility of silver bromide in—log moles AgBr dissolved in 1000 grams of approximately 0.2 molar Na_2SO_3 at 25° C. ⊙ Solubility of AgBr in water.

pH 4.5. Another special mechanism requires the assumption of oxidation of the ion HSO_3^- to a monothionate free radical by photolytically produced bromine atoms in the immediate vicinity of a sub-latent image speck.

The monothionate hypothesis would seem to require as a corollary that the maximum effect with sulfurous acid should be obtained by having it present in sufficient concentration at the time (moment) of exposure, i.e., of formation of latent image, or equivalently, of sub-latent image, and thereby of release of *atomic bromine*.

Although by *extrapolation backward*, the decay curve (Figs. 7 and 8) might be held to indicate this, the fact remains that there is no evidence for a hypersensitizing effect, as compared to a "latensifying," i.e., a post-exposure effect.

Provisionally, it appears that the less specific acidic action, releasing surface Ag^+ ions, must be preferred as the "latensification" mechanism.

TABLE II

Acid			
Monobasic	pk_a		
x Salicylic	3.0		
Nitrous	3.3		
✓ Formic	3.7		
✓ Acetic	4.7		
✓ Propionic	4.8		
Dibasic	pk_{a_1}	pk_{a_2}	k_{a_1}/k_{a_2}
✓ Oxalic		3.9	1,000
✓ Sulfurous		5.3	3,400
x Succinic	4.0	5.3	17
x Glutaric	4.3	5.5	16
x Malonic	2.7	5.4	460

✓ Reported effective.
x Reported not effective.

In terms of this, the "decay" might be concerned with the diffusion away of silver atoms, but since the beginning of effective latensification would not be identical with the "moment of exposure," there would be no necessity for a hypersensitizing effect to be manifest, as indeed is apparently the case.

In connection with acid latensification, the data shown in Table II on the dissociation constants of "weak" acids are of interest.[25]

IV. OXIDANTS AS LATENSIFIERS, INCLUDING PEROXIDES.

While the first definitely claimed "latensification" was by the use of an auxiliary "flash" exposure to light after the original exposure,[5] the influence of hydrogen peroxide (H_2O_2) in this function was apparently first observed by Lüppo-Cramer [2] and thereafter subject to more detailed study, by Wightman, Trivelli and Sheppard [3] and by Wightman and Quirk.[3] Observations of Lüppo-Cramer [26] on a latent fogging action of other oxidants, such as nitric acid, and permanganate of potash, have been confirmed and extended by us to latensification including the case of N_2O_4 as a vapor, at concentrations ranging from 1 in 10,000 to 1 in 1,000,000. In all such cases, however, the "latensification" is poorly reproducible, and critically liable to be replaced by destruction of latent image and/or by "fog," i.e., by a mere increase of density without a significant differential in respect of the exposure to light.

The action of hydrogen peroxide is outstanding, for more than one reason. It is more clear-cut and controllable—in spite of its sensitivity—than that of the other reagents in this class. Owing to the ready production of peroxide by autoxidation of a variety of organic materials, it is always with us, and peroxide latensification is often to be looked for as a precursor of the famous "Russell" (fogging) effect. Explanations have varied, from a chemiluminescence to various chemical reactions. Of the latter, an important suggestion consists in a reaction with free bromide ions, reducing their concentration and converting the bromide ion to bromine, representable by the reaction [3]

$$H_2O_2 + 2\ \overset{-}{Br} + 2\ \overset{+}{H} \rightarrow Br_2 + 2\ H_2O.$$

Wightman and Quirk [3] formerly regarded this step as less important than the possibility of a chain reaction maintaining a certain steady state ratio of Br_2 to Br^- by the collateral reaction

$$H_2O_2 + Br_2 = O_2 + 2\ \overset{-}{Br} + 2\ \overset{+}{H}.$$

They considered the most important agent to be the molecular bromine, which was further supposed to act on a sub-latent image germ of Ag_2S: Ag, according to K. C. D. Hickman's hypothesis.[27]

The importation of bromine (Br_2) into the argument is supported by Lüppo-Cramer's [28] observation of an intensifying action of quite dilute bromine itself, which was confirmed by Wightman and Quirk. It was obviously inviting to regard all the oxidant actions as essentially equivalent to the conversion of bromide ions into bromine, the presence of a sufficient excess of bromide being supposed a *sine qua non* for this intensification.

We are by no means convinced that the production of bromine is essential. Not only is bromine itself an acceptor for bromine ions, forming the complex Br_3^-, but in any case the latensifying action of bromine has been given only a perfunctory examination. At present, a similar explanation for the action of oxidants to that given for organic acids seems reasonable, viz., mobilization of Ag^+ ions about a "germ," or sub-latent image speck, with the difference that the conditions are more critical, in view of the hazard of complete nullification of the immature speck. In this connection the probability of a more ready reducibility of "bare" * silver bromide (produced by bromination of Ag_2S or of Ag) over original gelatino-silver bromide should be considered.

V. AMMONIA AND AMINES.

The intensifying action [29] of gaseous ammonia, and of certain amines, is susceptible again of more than one explanation. One is denudation of a sub-nucleus, another is mobilization of Ag^+ ions. Assuming these to be protected in the grain surface by adsorbed amino-groups of gelatin or of imino-groups, displacement of these by free NH_3, forming mobile $Ag^+(NH_3)$ ions, would permit concentration of these about a sub-nucleus, with subsequent loss of ammonia. That this can take place in a much coarser form is demonstrated by the actual "development" of an image produced by ammonia fuming of higher exposures.[30]

In regard to the anomalous behavior of *oxidants* (H_2O_2, CrO_3, etc.), the possibility of some Ag^{++} or Ag^{+++} ions being formed should be considered.

Induction Period.

Whether a true or basic "grain" induction exists for development has been made doubtful by T. H. James' recent recasting of the theory of development.[31] As suggesting that this induction exists, one may cite the following phenomena:

1. "Light" development of x-ray-exposed material (Luther and Uschkoff, q. v.).[32]
2. "Heat" development of ultraviolet-exposed silver oxalate.

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* By this is meant silver bromide not protected by either bromide ions or by a colloid such as gelatin.

In these cases there is no question of an alien component—the developer—but an autochthonous process in the grain in which preformed nuclei exercise a definite (auto-) catalytic effect, and a true "grain" induction is manifest.

3. The observations of Sheppard and Trivelli on the rôle of large grains in photolysis—when large grains appear more sensitive here, corresponding to a "probability" regulated auto-catalysis of the print-out process.

In a more intensive investigation of hypersensitizing and latensifying procedures, the mercurial process seems particularly interesting and valuable. (i) Because it is anhydrous, it involves minimum accessory factors, while permitting differentiation from the action of light itself in auxiliary exposure processes. (ii) Further, it does not seem likely to interfere directly with either bromide-ion or gelatin-potential barriers in development. (iii) There seems little reason to suppose that it should modify the incidence of internal latent-image nuclei.*

With this in view, experiments have been made on *three* different types of emulsion, differing rather widely as to sensitizing and grain-character. They were (A) high-speed panchromatic negative, silver (iodo)-bromide, (B) motion-picture positive silver (iodo)-bromide, and (C) special experimental pure silver bromide, optically unsensitized.

Both on theoretical and practical grounds, the principal interest in hypersensitizing and latensification is for the under- or early-exposure stage, and at progressive low-intensity levels. Therefore, we have expressed the results in terms of density D vs. $I(t)$, that is directly against intensity for constant time, rather than against log E. In many cases it has been helpful to plot the first derivative, $\Delta D/\Delta I$, as a function of I, a quantity which is more perspicuously related to the photochemical susceptibility (although always of course viewed through the distorting and amplifying factor, development).

In general, it may be said that by keeping to the "toe" of the exposure curve, we approach more to the behavior of a one-grain layer, and avoid complications unnecessary to pure theory which are brought in by advancing to the region of so-called "correct" exposure.

In Figs. 10 and 11 are compared the effects of "hypersensitizing" and "latensification" with Hg vapor at time periods precluding (roughly) time factors of exposure to the vapor, with the H.-S. panchromatic emulsion. A result brought out by the derivative curves is to show how soon hypersensitization may yield to desensitization, as shown by the declining $\Delta D/\Delta I$ values. This is probably to be attributed to the desensitizing effect of competition between nuclei once the optimum—or at least the "optimum possibile"—has been reached.[11]

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* Its possible relation to Dr. M. L. Huggins' hypothesis of "latent-image" formation will be considered later.

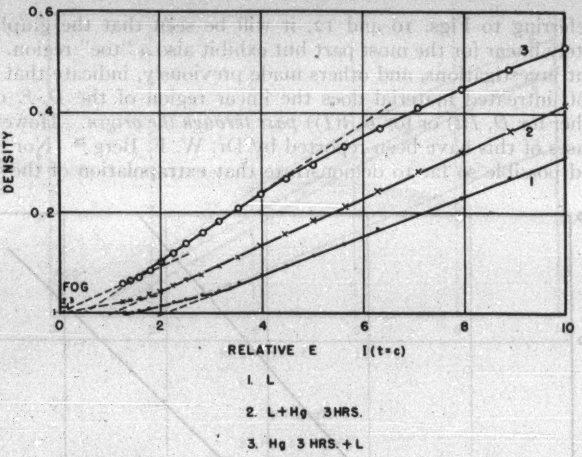

FIG. 10. Hypersensitization and latensification of a high-speed panchromatic negative, silver iodo-bromide emulsion with mercury vapor. Extrapolations to origin are hypothetical and questionable.

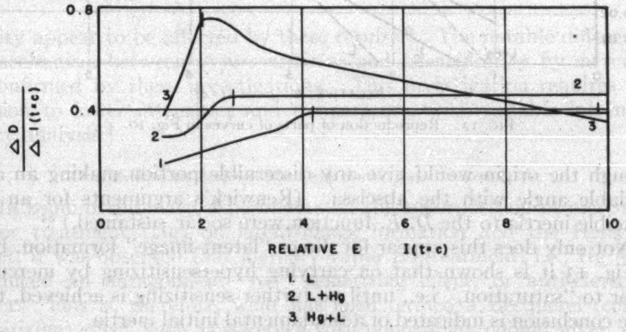

FIG. 11. First derivative of curves in Fig. 10.

Terminology.

At this time it appears desirable to explain certain symbols used for compactness in the graphic exposition. These are:

L, means latent image formed by exposure to light, without either hypersensitizing or latensification, i.e., the control.

Hg, refers to mercury vapor, so that Hg + L implies hypersensitizing, L + Hg implies latensification, each with mercury vapor. Again, H indicates exposure to red (Herschel) rays.

Referring to Figs. 10 and 12, it will be seen that the graphs are definitely linear for the most part but exhibit also a "toe" region. Our present investigations, and others made previously, indicate that in no case of untreated material does the linear region of the *D.-E* curve, (whether for *D*, *I*(*t*) or for *D*, *t*(*I*)) *pass through the origin.* However, a few cases of this have been reported by Dr. W. F. Berg.[33] Nor had it seemed possible so far to demonstrate that extrapolation of the "toe" through the origin would give any discernible portion making an appreciable angle with the abscissa. (Renwick's arguments for an irreducible inertia to the *D. E.* function were so far sustained.)[34]

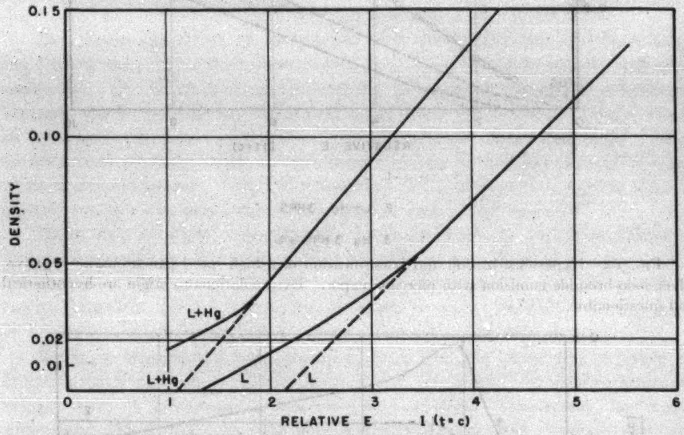

FIG. 12. Reproduction of parts of curves in Fig. 10.

Not only does this appear for direct "latent-image" formation, but in Fig. 13 it is shown that on carrying hypersensitizing by mercury vapor to "saturation," i.e., until no further sensitizing is achieved, the same conclusion is indicated of a fundamental initial inertia.

It is, therefore, the more important that further careful comparisons be made between "light"-latensified and mercury-"latensified" images on the same materials, and similarly for "light"-and mercury-hypersensitized images. The "structure" of the graphs of *D* vs. *E* on approach to zero, whether obtained by light alone, or by light *plus* mercury vapor, cannot yet be regarded as unambiguous, i.e., the appearance of segmented rather than continuous lines shows that unique and single layers are not yet segregated.

Certain hypothetical arguments[35] in favor of the sufficiency of 1 quantum (of blue light), 2 quanta, 3 quanta per grain to effect develop-

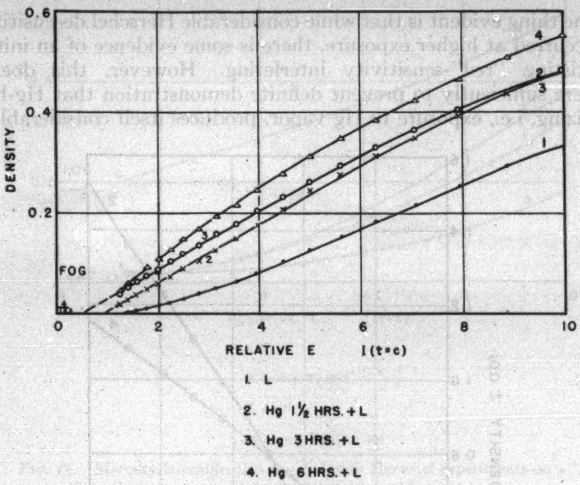

FIG. 13. Hypersensitization of a high-speed panchromatic negative, silver iodo-bromide emulsion for varying periods of mercury vapor treatment.

ability appear to be affected by these results.[*] The notable difference in mechanism between *hypersensitizing* and *latensification* by mercury is confirmed by these investigations. This investigation requires extension to lower intensities and temperature, with suitable intermittency analysis.[†]

Herschel and Becquerel Effects with Mercury-Vapor Treatment.

In some preliminary experiments on the superposition of mercury-vapor treatment (Hg) on latent-image formation and the Herschel effect, it was observed that mercury-vapor pretreatment, i.e., Hg + L produced an antagonistic "red" sensitizing effect, or anti-Herschel effect. This is, therefore, what has been termed a Becquerel (color-sensitizing) effect, such as is known with photosilver, colloid silver, and with colloidal silver sulfide.[36]

The radiation used in the Herschel experiments was limited to radiations beyond 7400 Å by the following filter combination: One Wratten No. 25 and two Wratten No. 87 filters.

In Fig. 14 and Fig. 15 are given graphs of the experimental data with a motion-picture positive type of emulsion.

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[*] This is not to argue that the *possibility* that 1 quantum, 2 quanta, or 3 quanta may occasionally, under certain conditions, make a grain developable can be disproved by such results, but that the *probability* of this occurring may be diminished.

[†] Intermittency allows evidence of decay or growth, e.g., with rise or fall of temperature.

One thing evident is that while considerable Herschel desensitization has occurred at higher exposure, there is some evidence of an initial or pre-existing "red"-sensitivity interfering. However, this does not interfere sufficiently to prevent definite demonstration that Hg-hypersensitizing, i.e., exposure to Hg vapor, produces itself considerable red-sensitivity, so that in the "Herschel" exposure of the Hg-hypersensitized material very definite "antagonism" is shown.[37] In terms of an older photographic terminology, the mercury-vaporized material shows both a Herschel (desensitized) and a Becquerel (color-sensitized) effect, the one predominating at lower exposures, the other (H) at higher ex-

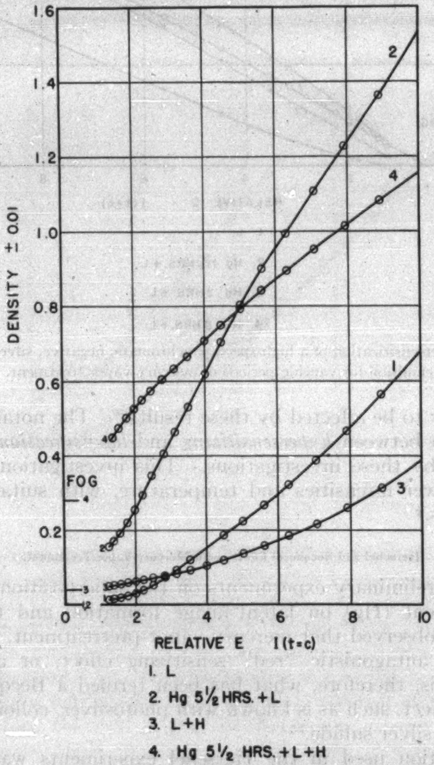

FIG. 14. Mercury hypersensitization coupled with Herschel experiments on a motion-picture positive silver (iodo)-bromide emulsion.

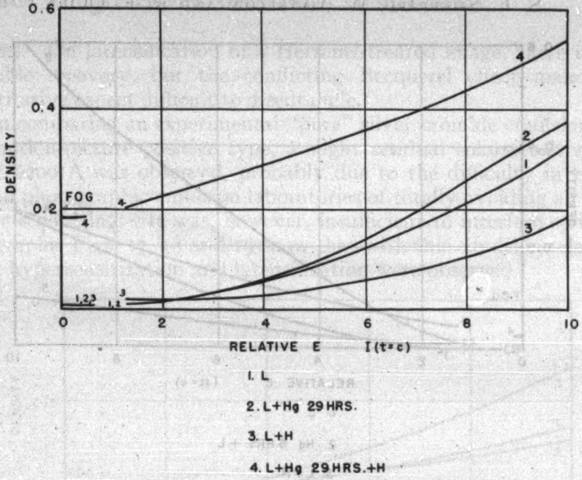

FIG. 15. Mercury latensification coupled with Herschel experiments on a motion-picture positive silver (iodo)-bromide emulsion.

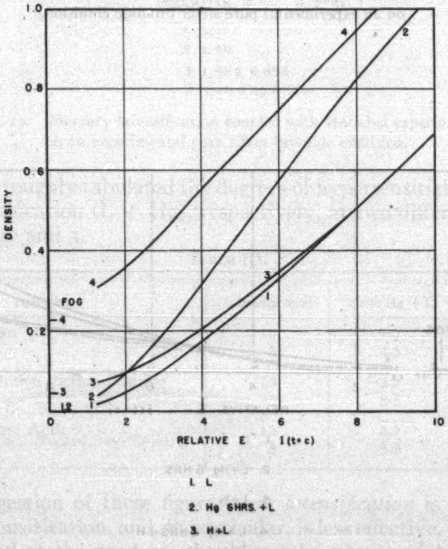

FIG. 16. Mercury hypersensitization coupled with Herschel experiments on a motion-picture positive silver (iodo)-bromide emulsion.

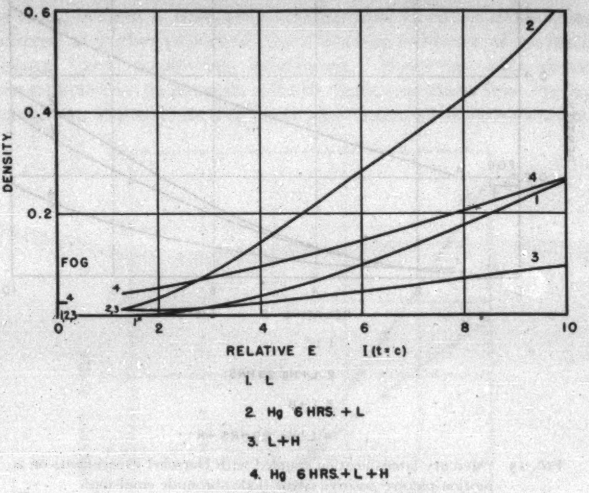

Fig. 17. Mercury hypersensitization coupled with Herschel experiments on an experimental pure silver bromide emulsion.

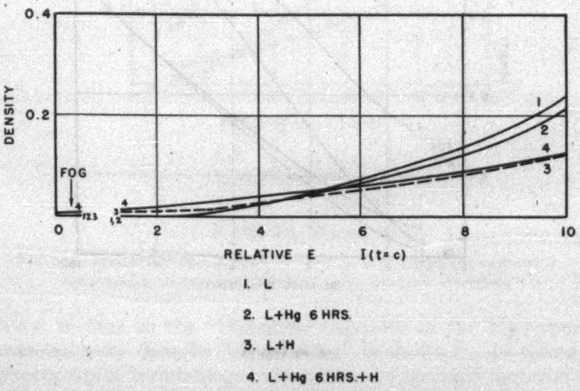

Fig. 18. Mercury latensification coupled with Herschel experiments on an experimental pure silver bromide emulsion.

posures. On latensification of a Herschel-treated image, there is considerable recovery, but the conflicting Becquerel effect makes the quantitative aspect difficult to disentangle.

On comparing an experimental "pure" silver bromide emulsion with the motion-picture positive type, a slight residual color-sensitivity to about 6200 Å was observed, probably due to the difficulty in experimental photographic emulsion laboratories of totally avoiding all traces of dye-sensitizing. It was, however, insufficient to interfere seriously. The graphs, Figs. 17, 18 and 19 show that with this emulsion relatively slight hypersensitization and latensification were observed.

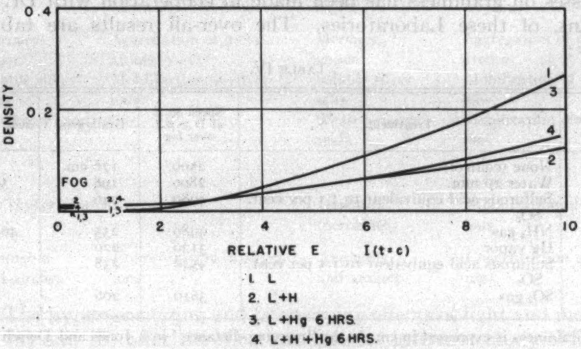

FIG. 19. Mercury latensification coupled with Herschel experiments on an experimental pure silver bromide emulsion.

We have roughly tabulated the degrees of hypersensitizing (Hg + L) and of latensification (L + Hg), respectively, at two different intensity levels, viz., 10 and 3.

TABLE III.

Emulsion	Intensity level	Ratio Hg + L	Ratio L + Hg
Experimental Pan	10	1.7	1.3
	3	4.3	2.2
Experimental Motion Picture Positive	10	2.2	1.2
	3	5.5	1.0
Experimental Pure AgBr	10	2.2	(1.0)
	3	5.5	(1.0)

The suggestion of these figures that *latensification* is less effective than hypersensitization, and, in particular, is less effective, the lower the original speed of the product, should not be given weight at present. What does seem significant is the indication that *hypersensitizing* is about equally evident for three different emulsions of very different types and speeds.* More cannot be concluded until the experiments are pushed to considerably lower intensity levels, and until greater variation in the development is exercised.

Latensification and Graininess.

A practically important procedure of either hypersensitizing or of latensification should produce the rise of speed claimed without increasing graininess, or reducing resolving power.

A preliminary examination of the effect of a number of latensification processes on graininess has been made in coöperation with Dr. G. C. Higgins, of these Laboratories. The over-all results are tabulated below:

TABLE IV.

Sample no.	Treatment	Speed 30/E at $D = 0.2$ over fog	Graininess†	lines/max. mm.
1	None (control)	2500	176 cm.	60
2	Water 20 min.	2800	198	50/55
3	Sulfurous acid equivalent to 1.1 per cent. SO_2	4980	246	50
4	NH_3 gas	4980	235	40/45
5	Hg vapor	3120	220	40
6	Sulfurous acid equivalent to 1.5 per cent. SO_2	4540	238	45
7	SO_2 gas	3610	206	45

† Graininess is expressed in cm. as the "merging distance" in a Jones and Deisch type of graininess measuring instrument.

These data are not presented as expressing finality in regard to the relationship between the latensification increments (*a fortiori*, of hyperintensification) of speed and grain. But they do indicate that, in general, what is gained in speed is at the price of coarser grain and lowered resolving power or definition. In these cases this is probably not due to any obscure "action" of the agent upon the grain (of silver halide) nor upon the development process (hence upon the resultant silver grain of the image), but simply statistically by increasing the number of grains of a certain size-class brought into the arena at a given exposure time and intensity level.

Otherwise expressed, the evidence *so far*, from hypersensitizing and latensification, is that fundamentally and ultimately, photographic sensitivity is limited by grain-size or projective area. The grain-size area provides the amplifying feature. At the same time it reduces correspondingly the resolving power or definition, so that the simple limiting photographic law is:

$$\text{sensitivity} \times \text{resolving power} = \text{constant}.$$

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* The possibility that the limiting residual factor in sensitizing is grain-size or area is a feasible conclusion which is discussed later.

At present, the severe limitations to photography which this would seem to impose are relaxed by the actual gradients of tonality, or of light-intensity, which constitute our visual perceptions of objects—in so far as monochromatic—together with the further fact of color.

CONCLUSIONS.

1. Processes of hypersensitizing and latensification have been tentatively classified as below:

	Hypersensitizing		*Latensification*	
	Agent	*Mechanism*	*Agent*	*Mechanism*
(a)	Light	(crystallo) electronic	Light	(crystallo) electronic
(b)	Mercury vapor	Aggregation of metal atoms	Mercury vapor	Aggregation of metal atoms
(c)	Soluble silver salts	Mobilization of silver ions	Soluble silver salts	Mobilization of silver ions
(d)	*No (hyper) sensitizing*		Weak (organic) acids	Mobilization of silver ions
(e)	*No (hyper) sensitizing*		Oxidants (peroxides)	Mobilization of silver ions
(f)	Ammonia and amines	Concentration of silver ions	Ammonia and amines	Concentration of silver ions

2. The hypersensitizing and latensifying effects of light and mercury vapor (a) and (b) offer the most promise for intensive study of latent-image formation.

3. Herschel effects have been observed on mercury-latensified latent image, and also the production of long-wave (red) sensitizing by mercury vapor treatment, that is, of an antagonistic Becquerel effect.

The writers wish to acknowledge the helpful coöperation, both in discussion and in sensitometric practice, of several colleagues, and notably of Drs. J. Russell, G. C. Higgins and T. H. James.

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NONLINEAR SPRINGS.

BY

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The Problem. We are going to present a new method of attack on the nonlinear oscillatory equation

$$\ddot{y} + S(y) = 0. \tag{1}$$

This is the differential equation of motion of a unit mass oscillating under the action of the spring force $S(y)$. We assume that the spring is symmetric under tension and compression, meaning

$$S(-y) = -S(y). \tag{2}$$

The potential energy $U = U(y)$ stored up by the spring is given in terms of the deflection y by

$$U(y) = \int_0^y S(y)dy \tag{3}$$

whence

$$U'(y) = S(y), \qquad U(o) = 0, \qquad U(-y) = U(y). \tag{4}$$

The first integral of (1) is

$$\dot{y}^2 = v^2 - 2U(y) \tag{5}$$

in which the arbitrary constant of integration v is the initial velocity ($\dot{y} = v$ for $y = 0$). Evidently, $U(y)$ does not and may not involve v as a parameter because an absolute characteristic of the spring such as $U(y)$ could not depend on the special way the spring might be put to work.

Assuming that the quadrature required to formally integrate (5) is impractical, we propose to advance by a different method.

The Modifier and the Oscillator. Let us begin with an example: assume $S(y) = 0$ identically. Then (1) becomes $\ddot{y} = 0$, and $y = v(t - t_0)$ is the general solution. It may also be written as $\sinh y = \sinh v(t - t_0)$ or $\arctan y = \arctan v(t - t_0)$ or $\phi(y) = \phi(v(t - t_0))$. In the present example this modified implicit presentation is ridiculous because the explicit presentation $y = v(t - t_0)$ is simplest of all of them. This is so because the differential equation $\ddot{y} = 0$ is a triviality. But in cases of more involved differential equations with a complicated spring force function $S(y)$ the explicit presentation of the general solution as $y = y(t - t_0, v)$ may require the use of unfamiliar functions rather to be avoided, while a suitable implicit presentation such as

$$G(y) = vF(t - t_0, v) \tag{6}$$

might be less cumbersome. We are thus led to the idea of solving (1) for some function of y rather than for y itself. This practical convenience alone, however, would not warrant a discussion of the implicit form of presentation. A deeper interest should be aroused due to the fact that the implicit method has an intrinsic power of systematizing and classifying and actually enables us to solve (1) for quite a variety of special nonlinear springs. By the way, two nonlinear springs soluble by elementary functions appear in such a systematic investigation. Their diagrams (force $S(y)$ plotted against extension y) are characteristic of the stiff and soft types of actual springs. Because of their elementary character those two springs would make good examples for elementary books on vibrations. They are found under Nos. 1 and 2 in Table 1. As for nonelementary solutions of (1), elliptic functions supply a crop of them so abundant that only a part of it has been included in the present paper. It seems feasible to closely approximate an experimental spring diagram by some one of those solutions.

We propose to use the following terminology: "modifier of y" for $G(y)$, "oscillator in t" for $F(t, v)$. The oscillator is supposed to be a bounded periodic function of the time t. G^{-1}, the inverse of the modifier, has to be real and single valued in the range as covered by the right member in (6).

Norming of the Modifier and the Oscillator. Choosing the initial conditions

$$y = 0, \qquad \dot{y} = v \qquad \text{for} \qquad t = 0 \tag{7}$$

we obtain a solution of (1) that is an odd function of t,

$$y(-t, v) = -y(t, v) \tag{8}$$

because (1) and (7) are invariant under the transformation $(t, y) \rightarrow (-t, -y)$ on account of (2). With $t_0 = 0$ we rewrite (6) as

$$G(y) = vF(t, v). \tag{9}$$

To comply with (8) identically, we assume that G and F are odd functions in y and t:

$$G(-y) = -G(y), \qquad G(0) = 0, \tag{10}$$

$$F(-t, v) = -F(t, v), \qquad F(0, v) = 0. \tag{11}$$

For abbreviation, let us write

$$F(t, v) = F(t) \tag{12}$$

whence

$$F(-t) = -F(t), \qquad F(0) = 0. \tag{13}$$

Obviously, $F(t)$ involves v as a parameter. The solution (9) written now as

$$G(y) = vF(t) \tag{14}$$

complies with the first part of the initial conditions (7). To comply with the second part we differentiate (14) with respect to the time

$$G'(y)\dot{y} = vF'(t) \tag{15}$$

and norm the derivatives of G and F as follows:

$$G'(0) = F'(0) = 1. \tag{16}$$

We thus have

$$G(y) = y + A_3y^3 + A_5y^5 + \cdots, \tag{17}$$

$$F(t) = t + B_3(v)t^3 + B_5(v)t^5 + \cdots. \tag{18}$$

The power series in (17) is invertible and secures the existence of the inverse expansion

$$y = G + h_3G^3 + h_5G^5 + \cdots, \tag{19}$$

The coefficients h_n of that expansion do not involve v because the modifier, (17), does not.

The Design of Nonlinear Springs. The oscillator $F(t - t_0, v)$ is a periodic function of the time involving two constants t_0 and v. With respect to t_0 as an arbitrary constant of integration the periodic oscillator appears as the general solution of an oscillatory equation of the type

$$F'^2 = 1 - a_2(v)F^2 - a_4(v)F^4 - \cdots \tag{20}$$

in which the coefficients a_n evidently will have to involve v because F does so.

For any particular chosen modifier $G(y)$ of the type (17) a unique expansion

$$G'^2 = 1 - b_2G^2 - b_4G^4 - \cdots \tag{21}$$

exists on account of (19). The coefficients b_n do not involve v because the modifier $G(y)$ does not.

Computing the spring energy function $U(y)$ from (5) with the aid of (15), (20), (21) and (14) we obtain

$$2U(y) = v^2 \frac{\left(\frac{a_2(v)}{v^2} - b_2\right) G^2(y) + \left(\frac{a_4(v)}{v^4} - b_4\right) G^4(y) + \cdots}{G'^2(y)}. \tag{22}$$

Now, since the spring energy function $U(y)$ does not involve the arbitrary constant of integration v, *the right member in* (22) *may not depend on* v. Consequently,

$$v^2\left(\frac{a_n(v)}{v^n} - b_n\right) = c_n, \qquad n = 2, 4, 6, \cdots, \tag{23}$$

where the c_n do not depend on v. Solving for the $a_n(v)$, we find

$$a_n(v) = \left(\frac{c_n}{v^2} + b_n\right) v^n, \qquad n = 2, 4, 6, \cdots. \tag{24}$$

The spring energy function is now expressed as

$$2U(y) = \frac{c_2G^2(y) + c_4G^4(y) + \cdots}{G'^2(y)}. \tag{25}$$

We are now in a position to "design" special soluble nonlinear springs by proceeding as follows: starting out with an arbitrarily assumed set of values for the coefficients b_n we obtain the modifier $G(y)$ from (21). Next, assuming another arbitrary set of values for the coefficients c_n we obtain the spring from (25) and (4). Computing the values of the coefficients $a_n(v)$ from (24) and then solving (20), we obtain the oscillator $F(t, v)$. After which we write down the general solution of (1) as given by (6) and repeated here:

$$G(y) = vF(t - t_0, v). \tag{26}$$

It is seen that in the described procedure the spring function is determined jointly by the modifier and the choice of the values of the c_n. This happens before the oscillator enters the picture. The oscillator is computed subsequently to fit the chosen spring-modifier combination. We obtain different oscillators for the same spring if we use different modifiers. Properly applied, this simplifies the ultimate presentation of the general solution and its analysis.

New Elementary Springs. If we go as far as the terms in squares in (20), (21) and (25) only ($a_n = b_n = c_n = 0$ for $n > 2$), we obtain the modifiers $\sin y$ and $\sinh y$ and the oscillator $(1/p) \sin pt$. The corresponding nonlinear spring force functions are

$$S(y) = \frac{\sin y}{\cos^3 y} \qquad \text{(very stiff spring)}, \tag{27}$$

$$S(y) = \frac{\sinh y}{\cosh^3 y} \qquad \text{(very soft spring)}. \tag{28}$$

The respective general solutions, with v for the initial velocity, are

$$\sin y = \frac{v}{\sqrt{1 + v^2}} \sin (\sqrt{1 + v^2}t), \tag{29}$$

$$\sinh y = \frac{v}{\sqrt{1 - v^2}} \sin (\sqrt{1 - v^2}t). \tag{30}$$

The above gives us two new nonlinear springs soluble by elementary functions. The existence of such springs has apparently been overlooked in engineering literature on nonlinear vibrations.

Simple Elliptic Springs. If we go as far as the terms of fourth degree in (20), (21) and (25) ($a_n = b_n = c_n = 0$ for $n > 4$), we obtain solutions in terms of the Jacobian elliptic functions $sn(y, k_1)$, $sn(y, k_1)/dn(y, k_1)$, $sn(y, k_1)/cn(y, k_1)$ for the modifier $G(y)$, and $(1/n)\, sn(nt, k)$, $(1/n) sn(nt, k)/dn(nt, k)$ for the oscillator $F(t, v)$. A partial elementarization occurs as the elliptic function in the modifier degenerates. The result then is an elementary spring force function served by an elliptic oscillator (such as in the classical case of the pendulum). In the

TABLE 1

	$2U(y)$	$S(y)$	SOLUTION OF (1) IN FORM $G(y) = vF(t, v)$	K	n
1	$\tan^2 y$	$\frac{\sin y}{\cos^3 y}$	$\sin y = \frac{v}{\sqrt{1+v^2}} \sin nt$	------------	$\sqrt{1+v^2}$
2	$\tanh^2 y$	$\frac{\sinh y}{\cosh^3 y}$	$\sinh y = \frac{v}{\sqrt{1-v^2}} \sin nt$	------------	$\sqrt{1-v^2}$
3	$\sin^2 y$	$\frac{\sin 2y}{2}$	$\sin y = K \cdot \mathrm{sn}\, nt$	v	1
4	$\sinh^2 y$	$\frac{\sinh 2y}{2}$	$\tanh y = K \cdot \mathrm{sn}\, nt$	$\frac{v}{\sqrt{1+v^2}}$	$\sqrt{1+v^2}$
5	s^2	scd	$K_1^2 \frac{s}{d} = K \cdot \mathrm{sn}\, nt$	$\frac{K_1^2 v}{\sqrt{1-K_1^2 v^2}}$	$\sqrt{1-K_1^2 v^2}$
6	$\frac{s^2}{d^2}$	$\frac{sc}{d^3}$	$s = K \cdot \mathrm{sn}\, nt$	$\frac{v}{\sqrt{1+K_1^2 v^2}}$	$\sqrt{1+K_1^2 v^2}$
7	$\frac{s^2}{c^2}$	$\frac{sd}{c^3}$	$K_1 s = K \cdot \mathrm{sn}\, nt$	$\frac{K_1 v}{\sqrt{1+v^2}}$	$\sqrt{1+v^2}$
8	$y^2 - \frac{y^4}{4}$	$y - \frac{y^3}{2}$	$y = (\sqrt{1+v} - \sqrt{1-v})\, \mathrm{sn}\, nt$	$\frac{1-\sqrt{1-v^2}}{v}$	$\frac{\sqrt{1+v} + \sqrt{1-v}}{2}$
9	$y^2 + \frac{y^4}{4}$	$y + \frac{y^3}{2}$	$y = \frac{v}{n} \cdot \frac{\mathrm{sn}\, nt}{\mathrm{dn}\, nt}$	$\sqrt{\frac{1}{2} - \frac{1}{2\sqrt{1+v^2}}}$	$\sqrt[4]{1+v^2}$
10	$\frac{y^4}{4}$	$\frac{y^3}{2}$	$y = \frac{v}{n} \cdot \frac{\mathrm{sn}\, nt}{\mathrm{dn}\, nt}$	$\frac{1}{\sqrt{2}}$	$\sqrt{v}$

general non-degenerate case the presence of a parameter (modulus) k_1 in the modifier and in the spring force function gives rise to a variety of springs which may be used for curve fitting. Essentially, three types of springs arise. If we use the abbreviations

$$s = sn(y, k_1), \qquad c = cn(y, k_1), \qquad d = dn(y, k_1) \tag{31}$$

we may characterize those springs by their energy functions as follows:

$$2U(y) = As^2 + B\frac{s^2}{d^2}, \qquad As^2 + B\frac{s^2}{c^2}, \qquad A\frac{s^2}{d^2} + B\frac{s^2}{c^2}. \tag{32}$$

Each spring characteristic (32) depends on three independent parameters A, B, k_1. For an actual exposition we will have to limit ourselves and consider the "simple" one-term springs only. We introduce them in normed form as

$$2U(y) = s^2, \frac{s^2}{d^2}, \frac{s^2}{c^2}. \tag{33}$$

These simple springs still involve one parameter (the modulus k_1) suitable for curve fitting. Furthermore, certain limiting processes performed on (32) give rise to Hooke's linear spring and to three algebraic nonlinear springs which can be normed as follows:

$$2U(y) = y^2 - \tfrac{1}{4}y^4, \qquad y^2 + \tfrac{1}{4}y^4, \qquad \tfrac{1}{4}y^4. \tag{34}$$

All data pertaining to simple elliptic and algebraic springs and their solutions are compiled in Table 1. Included also are all possible partial and complete elementarizations occurring as one or both elliptic functions involved degenerate into circular or hyperbolic functions. Replacing t by $t - t_0$ gives the general solution of (1) in each case.

Combined Elliptic Springs. As already mentioned, Table 1 is based on the restricted choice of springs (33) and so does not exhibit all possible elliptic springs. An analysis of the general case (32) not shown here augments the elliptic collection by seven more types. The count includes degenerates. The results, too lengthy for a complete citation, can be readily derived by using the modifiers according to Table 2 in combination with either oscillator $(1/n)\, sn\, (nt, k)$ and $(1/n)sn(nt, k)/dn(nt, k)$. Both oscillators are required by each modifier to cover completely the range of coefficients in the spring energy function which make that function positive definite relative to y.

Graphs of Simple Elliptic Springs. The three heavily drawn curves in Figure 1 marked 1, 4, 3 are the graphs of the springs 1, 4, 3 from Table 1. The space between 1 and 4 is filled with the family of springs 7. The parameter in 7 is k_1. The extremes in 7, 1 and 4, are obtained with the use of the values 0 and 1 for k_1. 1 and all members in 7 proper have y bounded by a vertical asymptote, while 4 has none. The space between 4 and 3 is filled with the family of springs 6. The

TABLE 2

No.	Modifier	Spring Force
11	$\sin y$	$A\frac{\sin y}{\cos^3 y} + B\sin 2y$
12	$\tan y$	$A\sin 2y + B\sin 4y$
13	$\sinh y$	$A\frac{\sinh y}{\cosh^3 y} + B\sinh 2y$
14	$\text{Tanh}\, y$	$A\sinh 2y + B\sinh 4y$
15	$\text{sn}\, y \quad (= s)$	$A\frac{sc}{d^3} + B\frac{sd}{c^3}$
16	$\frac{\text{sn}\, y}{\text{dn}\, y} \quad \left(= \frac{s}{d}\right)$	$A\, scd + B\frac{sd}{c^3}$
17	$\frac{\text{sn}\, y}{\text{cn}\, y} \quad \left(= \frac{s}{c}\right)$	$A\, scd + B\frac{sc}{d^3}$

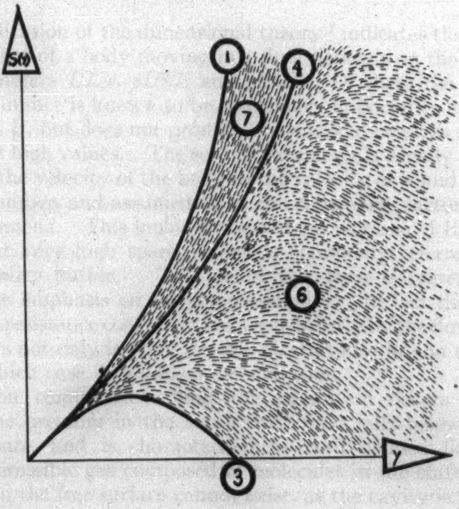

FIG. 1

parameter in 6 is k_1. The extremes in 6, 3 and 4, are obtained with the use of the values 0 and 1 for k_1. The curves 6 interpolate between the circular and hyperbolic sines of 3 and 4. Each one reaches a maximum and then drops down to zero. The family of springs 5 is of a very soft type, and so is the elementary spring 2 obtainable with $k_1 = 1$ from the family 5. We have not included 5 and 2 in Figure 1, and we equally refrain from drawing the cubical parabolas of 8, 9 and 10.

Numerical Tables of Elliptic Functions. L. M. Milne-Thomson: Die Elliptischen Funktionen von Jacobi, Berlin, Julius Springer, 1931, XIV + 69 pages.

AIR FLOW SEPARATION AT HIGH SPEED.

BY

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SUMMARY.

The resistance coefficient of a body moving in a fluid depends on Reynolds Number R, Mach Number M and the parameter gL/U^2, which is customarily neglected in view of small weight of the air. Here L denotes a characteristic length; U denotes the body's speed of translation. The author points that dimensional deduction of this parameter does not limit it to the acceleration of gravity, and that the resistance coefficient is affected by the general acceleration to which the air is subjected. Evaluation of the acceleration of the air flowing about spheres puts this parameter in the form L/R, where the characteristic length L is interpreted as the mean free molecular path. Large and small spheres were found to have widely different values of the pressure coefficient $\Delta p/q$ for the same Reynolds Number or Mach Number. Here Δp denotes the difference in pressure between front stagnatian point and the rear portion of the sphere, and q denotes the dynamic pressure. The plot of $\Delta p/q$ against the parameter L/R removes this confusion. The low values of $\Delta p/q$ are found to be associated with L/R below a certain critical value, and high values of $\Delta p/q$ with L/R above the critical value, which apparently indicates the condition under which the flow separation takes place. Attention is called to the effect of air pressure on the separation as shown by the parameter L/R, and its possible bearing on the drag in high altitude flying.

The application of the dimensional theory [1] indicates that the resistance coefficient of a body moving in a fluid depends on the non dimensional parameters UL/ν, $\rho U^2/E$ and gL/U^2. Of these the first one or Reynolds Number is known to be of primary importance at low values of the speed U, but does not produce any marked changes in resistance coefficient at high values. The second parameter is usually expressed as the ratio of the velocity of the body to the velocity of sound U/a, known as Mach Number, and assumed to be the controlling factor for all high speed phenomena. This includes the sudden increase of the resistance coefficient at very high speed, which is commonly referred to as the "compressibility burble." The use of this term is regrettable, as it places undue emphasis on the compressibility. In fact the sudden increase of the resistance coefficient is caused directly by the flow separation which occurs not only in compressible air, but also in non compressible water, in which case it is known as cavitation.

In a non compressible fluid the cavitation occurs presumably wherever the pressure in the accelerated fluid falls below the hydrostatic pressure, and is characterised by well defined liquid suface. In the compressible gas composed of molecules in the state of continuous agitation the free surface cannot exist, as the cavity is immediately filled up with molecules, which however no longer partake in the streaming motion of the surrounding fluid. The would be cavity is therefore filled with the gas in which the pressure cannot be predicted a priori. In the study of the separation of the gas at high speed it is therefore in order to assume that it is an unknown function of some parameter such as Mach Number. The Mach Number, however, represents merely the ratio of velocities, and does not contain the size of the body, while in certain cases of sphere tests the size of the sphere was responsible for large changes in the resistance coefficient at the same Reynolds Number or Mach Number, u/a. This is shown by the curves of Fig. 1 in which the pressure coefficient $\Delta p/a$ is plotted against the Mach Number. The latter is referred to the maximum local velocity u of the air at the periphery of the sphere, and is calculated on the assumption of the potential flow. These curves are based on the sphere tests[2,3] in various wind tunnels of the National Advisory Committee for Aeronautics, and the following table gives the key to various letter designations.

Designation	Number of points on the plot	Sphere diameter in inches	Wind tunnel
a	1	2	Variable density at pressure of 6 atmospheres.
b	1	12	20 ft.
c	3	10	7x10 ft., 20 ft. and full size.
d	2	8	7x10 ft. and full size.
e	1	6	20 ft.
f	curve	4	24″ high speed.
g	"	4	8 ft. high speed.
h	"	2	8 ft. high speed.
i	"	2	24″ high speed.

The inspection of Fig. 1 reveals three striking facts:

a. There is gradual increase of pressure coefficient with Mach Number.

b. There are no conspicuous or sudden discontinuities at the velocity of sound or $u/a = 1.0$.

c. The data appear to be arranged in two groups: the high coefficient group represented by the curves *i* and *h*, and the low coefficient group represented by all other points and curves. The portion of the curve *g* shown in dotted lines appears to represent a transition from the low coefficient to high coefficient groups, and is characterized by certain instability giving two readings for the same value of u/a.

PARAMETER gL/U^2—EFFECT OF ACCELERATION.

Figure 1 shows that there is unmistakable dependence of the pressure coefficient on the Mach Number, but that there must be also some other effect which determines the subdivision of data into low and high coefficient groups. This observation makes it desirable to investigate the significance of the third parameter gL/U^2. It is usually written with the acceleration of gravity *g*, and is followed by the discussion of its importance in the case of wave making resistance in water, in which case it is known as Froude's law of corresponding speeds. Concerning the air resistance it is stated that due to small weight of the air the forces due to the acceleration of gravity are evidently of no importance. This customary attitude is in error, as the derivation of the parameter by dimensional reasoning does not depend specifically on the acceleration of gravity, but generally on the acceleration, and the term should be written AL/U^2, where A denotes the local fluid acceleration regardless of the force producing it. The application of this parameter to accelerating flow is self evident. But even in the case of steady flow with uniform velocity, the air is subjected to accelerations when it meets an obstracle. It is decelerated in approaching the stagnation point, accelerated to the velocity exceeding the original one in flowing around the body, and again is decelerated at the rear part of the body. It is a matter of common experience that certain loss of a moving body's energy occurs whenever the fluid is subjected to acceleration, and therefore increase of the body's drag or pressure coefficient can be expected.

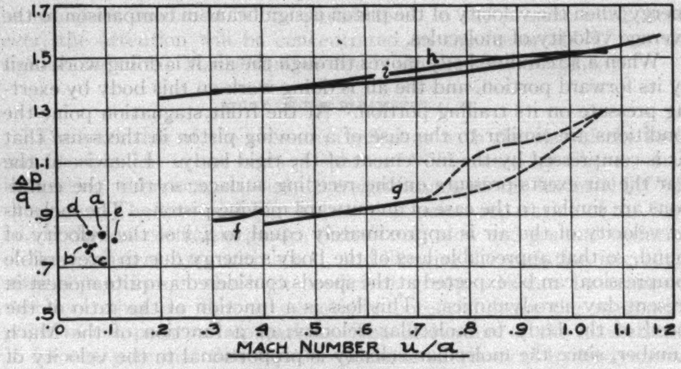

FIG. 1. The pressure coefficient $\Delta p/q$ for spheres plotted against the Mach Number based on the maximum local velocity of air.

In the classical hydrodynamic theory the fluid is assumed to be perfect, which is defined as being non viscous. As far as high speed air flow is concerned, a more important definition of the perfect fluid is contained in the assumption that changes of the energy from kinetic to potential (pressure) and vice versa occur simultaneously with the changes in the geometry of the flow, and without loss of the aggregate energy. In the compressible gas such as air this is not the case. The air is composed of molecules which are in constant movement of thermal agitation, and the static pressure is defined as the momentum carried by these molecules across a plane surface of unit area.[7] This pressure is equal to the pressure against the adjacent rigid surface only if the surface is stationary with respect to the mass of the gas, or in the particular case of the piston in a cylinder, when the piston is not moving. When the piston is moving and compressing the gas, the pressure on it is greater than static, and when it is moving in the opposite direction and the gas is doing work on it, the pressure is less than static. This phenomenon, known as "irreversible compression,"[4] results in loss of energy when the velocity of the piston is significant in comparison to the average velocity of molecules.

When a streamline body moves through the air it is doing work on it by its forward portion, and the air is doing work on this body by exerting pressure on its trailing portion. At the front stagnation point the conditions are similar to the case of a moving piston in the sense that air is compressed by the movement of the rigid body. Likewise at the rear the air exerts pressure on the receding surface, so that the conditions are similar to the case of an outward moving piston. The molecular velocity of the air is approximately equal to 4/3 of the velocity of sound, so that appreciable loss of the body's energy due to irreversible compression can be expected at the speeds considered as quite modest in present-day aerodynamics. This loss is a function of the ratio of the speed of the body to molecular velocity, or a function of the Mach Number, since the molecular velocity is proportional to the velocity of sound. The increase of the pressure coefficient resulting from the above loss of energy of a free-moving body is shown by the steady inclination of all curves on Fig. 1.

IRREVERSIBLE WORK OF KINETIC ENERGY.

The compression of the gas in a cylinder, or the compression of it at the stagnation point of the moving body, represents only one particular case of the loss of energy in irreversible compression. This principle can be more generally described as the "irreversible work," since it applies equally to the case in which the work done by a body increases the kinetic energy of the gas, or the kinetic energy is reduced by the amount of work done on a moving body. What is important is not the type of the energy undergoing the change, but rather the mechanism of transmitting the increment of energy needed to cause the change. Whether it is the pressure energy, or the kinetic energy, the change of it is the result of the same mechanism of numerous collisions between the molecules and the moving surface, and the loss of energy depends on the relative velocity of the surface and the mass of the air. The change of the kinetic energy of the air is manifested by the change of its velocity, and the loss of the kinetic energy in "irreversible work" depends on the rate of this change, or on the acceleration. The loss of the kinetic energy can be represented therefore as a function of the parameter AL/U^2 deduced by dimensional reasoning.

It is clear from the above that loss of energy or increase of the drag coefficient due to irreversible compression, expressed as a function of the Mach Number, and similar increase of the drag coefficient due to irreversible work in acceleration, expressed as a function of the parameter AL/U^2, represent two aspects of the same air flow around a body, and it is questionable whether the two can be entirely separated. The author is inclined to think that both parameters U/a and AL/U^2 should be somehow combined in one parameter. In the present work, however, the attention will be concentrated on the factor AL/U^2, as the significance of the Mach Number U/a is already well recognized.

STUDY OF THE PARAMETER AL/U².

The variation of the pressure coefficient with the size of the body was brought out in the tests of spheres [2,3] illustrated by Fig. 1. It is interesting, therefore, to study the significance of the factor AL/U^2 in this case. The curves of Fig. 1 show that before separation of the flow, i.e., in the low coefficient group, there is only slow and gradual variation of the coefficient $\Delta p/q$ with speed, and likewise the variation is gradual after separation in the high coefficient group. It can be assumed, therefore, that air flow is essentially potential from the stagnation point to the point of separation. The derivation of the acceleration A for the potential flow by the methods of classical hydrodynamics yields the expression of the general form:

$$A = K(U^2/R)f(\varphi),$$

where:

A = Acceleration of the fluid adjacent to the surface of the sphere.
K = Constant numerical coefficient.
R = Radius of the sphere.
φ = The angle between the direction of U and the radius passing through the point under consideration.

For the maximum acceleration the above expression becomes:

$$A = kU^2/R.$$

Dropping the constant, and substituting the value of $A = U^2/R$ into the factor AL/U^2, the simpler form L/R is obtained, or in more general form L/l.

In the factor L/l the l is by definition a linear dimension of the body, the radius R in case of the sphere. The L therefore can be interpreted as a certain linear property characteristic of the state of air. The study of the data plotted on Fig. 1 shows that the pressure coefficient $\Delta p/q$

displays but slow variation with speed in any one branch of the curve, but that it is markedly affected by the pressure: the test of the 2 inch diameter sphere at the atmospheric pressure give a high pressure coefficient, and the test of the same sphere at the pressure of six atmospheres in the variable density wind tunnel gives a low pressure coefficient. The linear characteristic of the air displaying the corresponding variations is found in the concept of the mean free path of the molecules [5,8], the value of which is determined by the expression[6]:

$$L = 1/\pi N\sigma^2,$$

where N is the number of molecules per unit of volume, and σ is the effective diameter of the molecule of the gas. If the discussion is limited to the air, σ becomes constant, while N is proportional to the density, and the expression for L becomes simply:

$$L = k/\rho,$$

where k is a constant coefficient which has the dimensions of m/l^2. For standard air at the pressure of 760 mm. Hg. and the temperature of 15° C. we have [9], averaging between oxigen and nitrogen, approximately:

$$L = 6.4 \times 10^{-6} \text{ cm.} = 0.21 \times 10^{-6} \text{ feet.}$$

APPLICATION TO EXPERIMENTAL DATA.

The author computed the factor L/R for the tests of spheres [2,3] in several wind tunnels, and plotted the pressure coefficient $\Delta p/q$ against L/R on Fig. 2. The tests on these spheres were conducted primarily for the purpose of study of variation of $\Delta p/q$ with Reynolds Number, and the published data [2,3] do not contain any information on the condition of the air. Therefore, in the compilation of Figs. 1 and 2, the air in the laboratory was assumed to be standard, and the velocity and the density of the air at the point of maximum local velocity at the sphere were calculated by using various assumptions depending on the type of the wind tunnel used. For the 24″ high speed wind tunnel the standard air at rest in the laboratory is assumed to be accelerated to the velocity U in the test section, and further accelerated to the maximum velocity $u = 1.5U$ in potential flow around the sphere. The static pressure at the velocity u is calculated from the relationship [11]:

$$u^2 = gBTf\,[1 - (p/p_o)^{2/f}], \tag{1}$$

where:

B = Gas constant for the air referred to the unit of weight.
p = The static pressure at the sphere at the point where the velocity u is maximum.
p_o = Static pressure of the standard air at rest.
f = Numerical coefficient taken as 7.

g = acceleration of gravity.
T = Absolute temperature taken as 518° F.

The density of the air at the velocity u and pressure p was computed from the equation of state for the streaming gas derived by the author in the previous work [10]:

$$pV = BT - u^2/fg, \tag{2}$$

where V is the specific volume $= 1/\rho$.

In case of the 8 ft. high speed wind tunnel it is assumed that the test section is in communication with the laboratory, and that air in it moving with velocity U has the standard pressure and temperature. The pressure of the air flowing at maximum velocity $u = 1.5U$ around the sphere is computed from the relationship [11]:

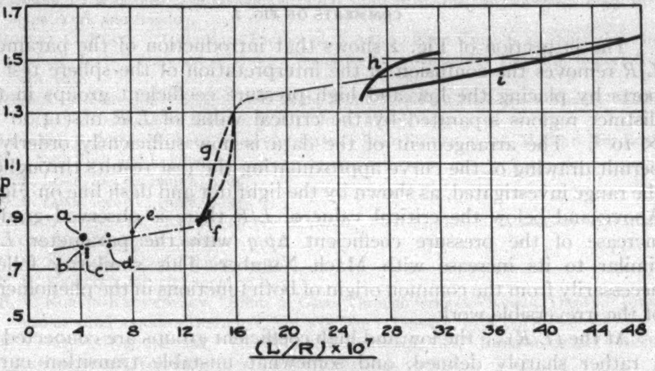

FIG. 2. The pressure coefficient $\Delta p/q$ for spheres plotted against the parameter L/R.

$$u^2 - U^2 = fgBT\,[(p_t/p_o)^{2/f} - (p/p_o)^{2/f}], \tag{3}$$

where:

p_t = the absolute static pressure of the air in test section taken as standard, or 2117 lbs./sq. ft.

p_o = the pressure of the air at rest, or approximately the pressure in the return duct, previously determined on basis of U using Eq. (1).

For the variable density wind tunnel it is assumed that velocities are sufficiently low, so that changes of density with speed can be neglected in the computation of the molecular free path L, and $l = 0.21 \times 10^{-6}$ feet corresponding to the standard air is merely reduced in the ratio of air pressures. Likewise the standard air value of L is taken for tests of 6 in. diameter and larger spheres in other wind tunnels. It is evident from the above description of the process used, that in absence of detail data on the state of air in the tests, and in view of the number of assumptions involved, the computations of the parameter L/R used in compilation of Fig. 2 are very approximate, as are also the computations of the Mach Number for Fig. 1. The reader is warned, therefore, against any attempt to make deductions from the details of the curves shown. Nevertheless, the fundamental dependence of the pressure coefficient $\Delta p/q$ on the parameter L/R is so clearly brought out by Fig. 2, that broad conclusions resulting from it are not likely to be affected by the probable inaccuracy of the abscissae.

COMMENTS ON FIG. 2.

The inspection of Fig. 2 shows that introduction of the parameter L/R removes the confusion in the interpretation of the sphere test reports by placing the low and high pressure coefficient groups in two distinct regions separated by the critical value of L/R of $(14 \text{ to } 16) \times 10^{-7}$. The arrangement of the data is now sufficiently orderly to permit drawing of the curve approximating the test results throughout the range investigated, as shown by the light dot and dash line on Fig. 2. Above and below the critical value of L/R there is observed gradual increase of the pressure coefficient $\Delta p/q$ with the parameter L/R, similar to its increase with Mach Number. This similarity follows necessarily from the common origin of both functions in the phenomenon of the irreversible work.

At the $(L/R)_{\text{crit.}}$ the low and high coefficient groups are connected by a rather sharply defined, and somewhat unstable transition curve, which occupies a very narrow range of L/R values, as compared to the total range used in the sphere tests. This transition range evidently indicates the separation of the flow at high speed due to the inertia of the fluid, as distinct from the separation at low speed due to viscosity, the critical speed for which is a function of Reynolds Number. In practical application the primary importance of the parameter L/l appears to be in indication of the critical speed at which the flow separation takes place in high speed range. The reference to Fig. 1 indicates that this critical speed is not defined by the Mach Number, as this was heretofore assumed.

The amount of experimental data available on the tests in the range of $(L/l)_{.\text{crit}}$ is not sufficient to discuss the practical application of this new parameter, but certain conjectures can be made, as suggested direction of research, rather than as definite assertion. It must be noted that in two dimensional flow the fluid acceleration is greater than in three dimensional one. Therefore the separation may be expected to occur at correspondingly lower value of $(L/l)_{\text{crit}}$. Furthermore the value of L, and the parameter L/l are increased in inverse proportion to the air density. This indicates that high speed flow separation may well occur within usable speed range in many parts of the airplane flying at high altitude, while it may be not indicated by the tests at low level. The maximum tip speed of propellers, for instance, may have to be reduced for sub-stratospheric flying. The normal wind tunnel technique at fairly high air speeds becomes more uncertain, as for the small model the high drag due to small Reynolds Number may blend into the high drag due to excessive value of the parameter L/l, as this has happened indeed in the tests of the 2 inch diameter sphere.

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A Stadium with an Air Supported Roof. (*Compressed Air Magazine*, Vol. 50, No. 7.)—Serious consideration is being given to the construction in Baltimore, Md., of a covered all-purpose stadium with a roof of sheet aluminum supported entirely by air pressure. The project calls for a structure large enough to seat 100,000 persons and suitable for year-round use. It is proposed to designate it as a state and city war memorial and to appoint for its administration a nonpartisan commission representing the religious, educational, business, political, sports, and cultural interests of Maryland. A General Stadium Committee of 78 leading citizens, divided into eight subcommittees for investigation of the various phases of the scheme, made a final favorable report on the project to Mayor Theodore R. McKeldin on May 1. This report will be supplemented later by additional engineering data and recommendations regarding the site.

Present plans are for a structure that will inclose an area 900 feet in diameter and cover thirteen acres. The continuous exterior wall will be of concrete and will rise well above the highest of the seating stands. On top of this wall will be a compression ring for the attachment of the aluminum roof, with provisions for an airtight seal. Internal air pressure will flex the roof upward to form a dome, with its center 170 feet above the playing-field level. This will give sufficient clearance for baseball, football, and all other forms of sport. There will be 93,000 fixed seats arranged in the conventional banks and in the shape of an oval, plus 7,000 portable seats that can be moved about as desired, depending upon the spectacle that is being staged. When not in use they will be stored under the permanent stands. Underneath the concrete seating structure will be ample space for the necessary operating machinery, offices,locker rooms, assembly rooms, a gymnasium, stables, kitchens and dining rooms, first-aid stations, toilets, etc.

Because steel sheets are vulnerable to attack by corrosion, it is proposed to use aluminum, which has the added advantage of being lighter. It has been computed that a pressure of only 9 pounds per square foot (approximately 1 ounce per square inch) would in that case suffice to support the huge roof of the stadium, as compared with 20 pounds for the same expanse if made up of steel sheets. That pressure is so low that it would have no physiological effect upon persons in the enclosure; in fact, they would not be aware of it. It could be induced by ordinary fans of the ventilator type.

R. H. O.

LOW TEMPERATURES AT LOW COST.

BY

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The advent of the war has brought many instances where it has been necessary to reach low temperatures. This has been required for innumerable processes and tests both in industry and in the laboratory. Low working-temperatures may be attained by the use of solid carbon dioxide (CO_2) commonly known as dry ice. This material has a sublimation temperature of about −78.5° C. (−109° F.). Where this material is available in quantities, required apparatus may be built which will use it to advantage. Such equipment may be simpler and less costly than conventional refrigeration machinery with its attendent evaporators, coils, valves and condensers.

Various means have been devised for the use of dry ice for testing, or other low-temperature work. In some cases the objects to be cooled are placed within the same enclosure or chamber as the dry ice itself. Stabilization of the temperature may thus be difficult. In some cases the dry ice is placed to one side of a baffle or partition. Small blowers or fans are then used for subliming and circulating the carbon dioxide. The usefulness of such units may, however, be limited. Such units may also contain heating devices for work requiring elevated temperatures. In such cases the dry ice is liable to dissipate rapidly, and may require frequent replenishment.

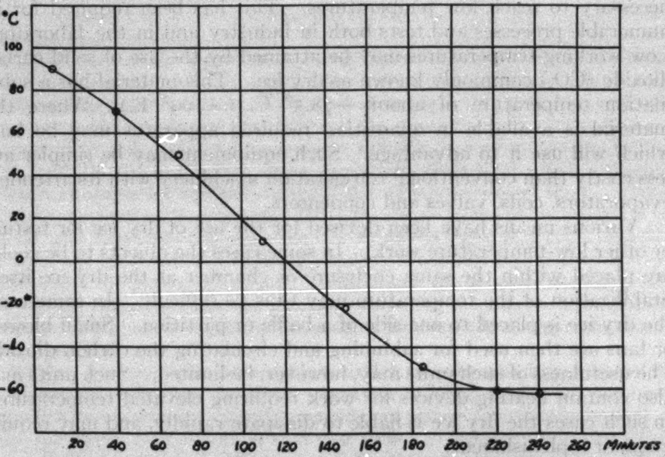
In conducting tests of prolonged duration (several hours) such test-chambers may become cumbersome and bulky. Sufficient space must be allowed for the dry ice. Provision must also be made to prevent freezing the blowers or fans. The entire apparatus must also be well insulated.

An example of dry ice equipment used for the purpose of testing small electronic parts on a mass-production basis is one of simple and unique design. Parts to be tested are placed on a tray (or shelf) supported within an insulated chamber. These parts are to be tested for their electrical characteristics under varying conditions of temperature from −60 to 100° C. (−76 to 212° F.). It is not required to stabilize the temperature at any given point, but to maintain a constant rate of change of about ⅔ C°. per minute, as shown in Fig. 1.

To accomplish this with time-cycle or program control equipment could in some cases be complicated and costly. In this application, however, semi-automatic equipment was installed in the Dobbs Ferry,

N. Y. plant of the North American Philips Co., Inc. Banks of multiple test-units were constructed, so simple to operate that five stations could be managed simultaneously by one attendent. This was accomplished by use of test chambers with close-coupled piping and positive-pressure blowers circulating carbon dioxide liberated from dry ice containers. To complete the test requirements, each station was accompanied by automatic electrical recording devices, shown in Figs. 5 and 6.

The test-cycle was arranged to begin at elevated temperature. The test chambers are prewarmed. Following this, gases are introduced at



Time-Temperature Curve. Slope of curve is a function of pipe size, blower speed and capacity, surface area of dry ice pieces, and adjustment of throttling valve.

FIG. 1. Graph showing time-temperature curve which the Temperature Reduction System tries to maintain.

a low temperature and controlled velocity. Continuous positive pressure is maintained. Thus moisture and ice formation are kept at a minimum. Prewarming may be accomplished by means of strip-heaters, lamps, or introduction of preheated air by means of auxilliary blowers, whichever is most convenient.

A single station set-up is shown diagramatically in Fig. 2. Assume for a moment that the piping were simplified, so that the outlet of chamber *A* is merely connected to the suction side of pump *C*. Imagine no other piping, except a connection from the pressure side of pump *C* to tank *B*, which is air-tight. From tank *B* a pipe leads to the inlet connection of test chamber *A*. When the pump is set in motion, the gases in the system are caused to circulate at high velocity. This in turn rapidly sublimes the dry ice, liberating CO_2 at sub-zero temperatures. The sublimed CO_2 is conveyed under pressure to the test chamber by insulated piping. With pump and piping of adequate size, the test chamber could be made to cool very rapidly.

Since it is desired to maintain a certain rate of temperature-change, a valve (*D*) is introduced, whereby gas flow may be readily controlled. The temperature rate of change could be controlled by other means, too, as for instance, by starting and stopping the motor, or by controlling its speed. The former is inefficient and the latter impracticable, since a-c power is used, and it was decided not to make an elaborate installation using d-c motors and speed regulators.

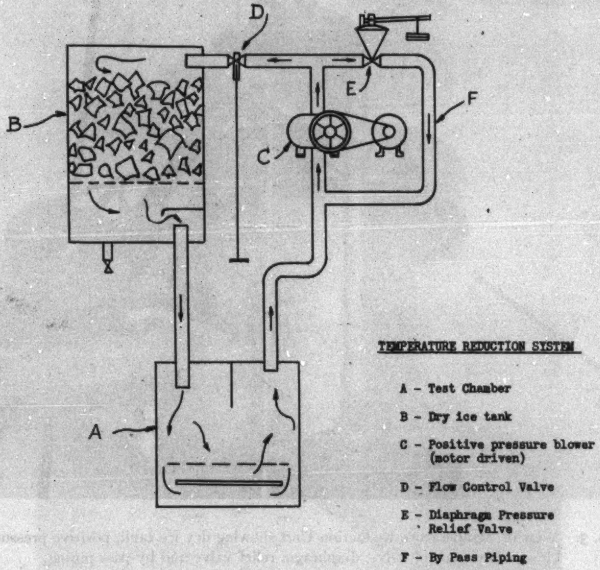

D
E
F
B
C
A
TEMPERATURE REDUCTION SYSTEM
A - Test Chamber
B - Dry ice tank
C - Positive pressure blower (motor driven)
D - Flow Control Valve
E - Diaphragm Pressure Relief Valve
F - By Pass Piping

FIG. 2. Diagram of Temperature Reduction Unit showing principal components.

Now let us consider the valving arrangement. Valve *D* is introduced at the inlet to tank *B*, Fig. 2. This valve is for regulating the flow of circulating gases. If valve *D* were closed and the pump running, pressure built up would have to be released. If a relief valve were installed between pump *C* and valve *D*, this would open up automatically and relieve the excess pressure to the atmosphere. However, since the pump is running at constant speed, it would continue to exhaust test chamber *A*, which, if not perfectly air-tight, would suck in air and would accumulate atmospheric moisture within. This may be undesirable and detrimental to the electronic devices being tested. Therefore, a weighted diaphragm relief valve *E* is placed in the piping system, with a by-pass returning to the inlet or suction side of the pump. Now, with the by-pass piping *F* of adequate size, all traces of suction at the chamber *A* are elminated when valve *D* is closed.

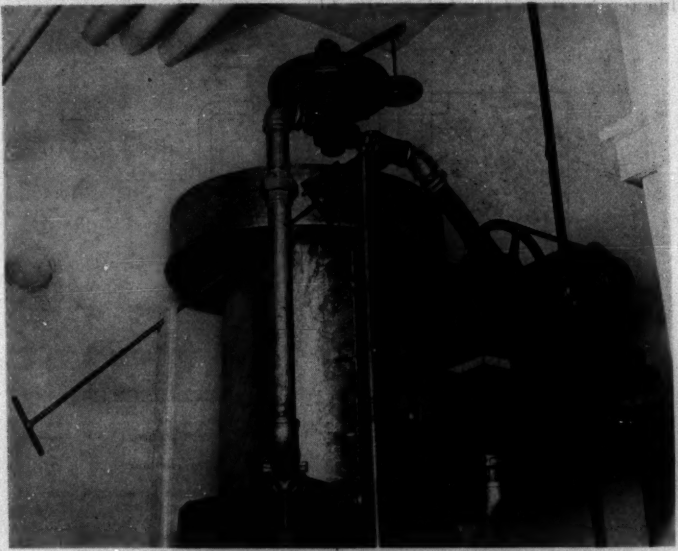


FIG. 3. View of Temperature Reduction Unit showing dry ice tank, positive pressure blower, flow control valve, diaphragm relief valve and by-pass piping.

Diaphragm relief valve *E* is normally held by weights in a closed position. When excessive pressure is built up at the inlet side, the diaphragm is expanded in a direction which forces up a plunger held by the weights. When the plunger, attached to the diaphragm, is lifted, the gases pass through the valve, the pressure is relieved, and the valve automatically remains open. Now, if valve *D* were to be partially closed (as when throttling flow to regulate temperature), valve *E* opens slightly to permit partial flow through the by-pass piping. Valve *E* will constantly regulate itself to open when valve *D* is closed, and to close when valve *D* is opened.

For throttling, or regulating the flow of gases, a valve of unique design was installed, *D*, Fig. 2. A length of rubber tubing (high grade, resilient and elastic), was securely attached to plain-end piping. The flexible tubing is squeezed between opposing members of a clamp, located midway of the length of tubing, and closing or opening of the clamp reduces or increases a clearance space within. Thus the passage of the gases may be conveniently controlled.

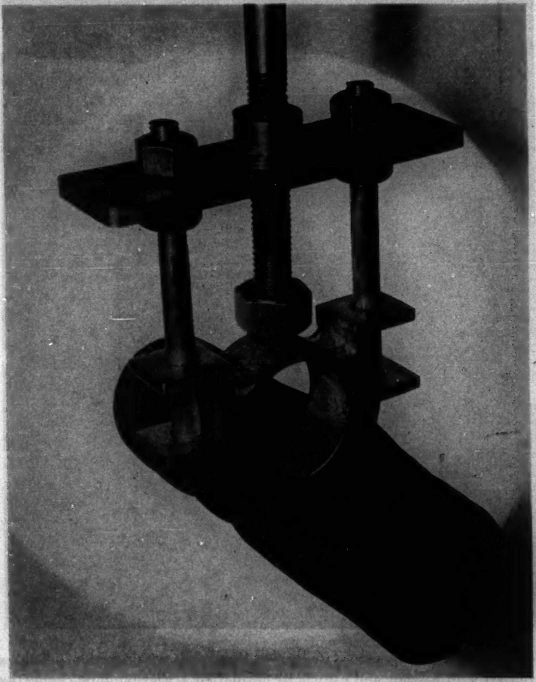


FIG. 4. View shows Flow Control Valve which accurately regulates orifice area by compression. It clamps the walls of a length of resilient, flexible tubing.

The rate of temperature change required in this application could be easily controlled by an occasional adjustment to the valve. The adjustment became a matter of routine that was easily acquired. It had repetitive characteristics, since a given setting resulted in a given flow. Construction of this valve is of utmost simplicity, as can be seen from Fig. 4.

The system in reality comprises a warmer and a colder side, the warmer side being the one having the pump, control valves, and attendant piping. The colder side of the system has in it the dry ice tank, the piping connecting the test chamber and, at times, the test chamber itself. Any valves placed in the latter part of the system would freeze

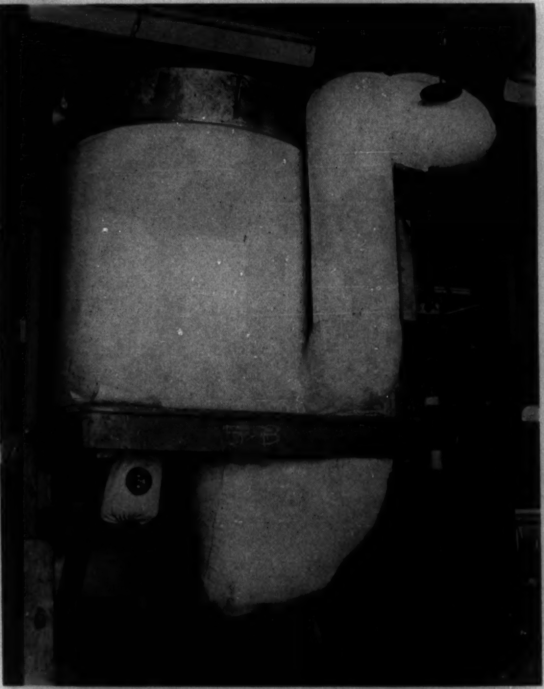


Fig. 5. View shows Temperature Reduction Unit ready for operation. Tank and piping have been covered with hairfelt and canvas for insulation. Flexible pipe connections for test chamber may be seen at bottom. Valve-wheel at left is for draining tank periodically when system is thawed out and cleaned. Motor starter and pilot light may be seen attached to righthand side of platform. Immediately above is the extension handle of the flow control valve, readily accessible to the attendant below. Electronic equipment for use in recording temperature-test results may be observed at the extreme right of the photo.

and become inoperative, unless heated by steam-jackets or otherwise. The throttling and pressure regulator valves are located in the warmest part of the system, which, together with the pump, could be operated continuously under normal ambient temperatures. The units do not freeze up on prolonged operation. The system may be operated on a 24 hour basis on hot to cold cycles.

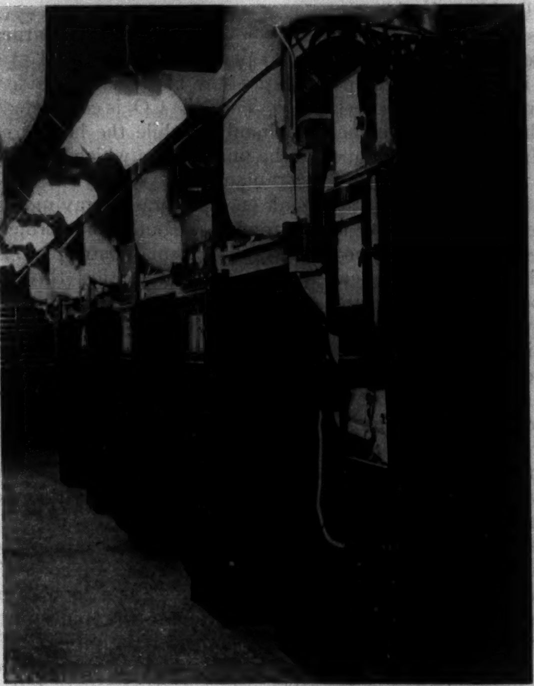


FIG. 6. View shows row of five stations for temperature-testing electronic parts. The pieces to be tested are placed on trays located inside the portable test chambers. After loading, the test-chambers are heated then cooled at a controlled rate, during which the test takes place. The results of the test are recorded on the charts in the test-racks.

The pump referred to is known as a "positive pressure blower." It operates on the principle of volumetric displacement. Two dumb-bell-shaped impellers mounted on parallel shafts, rotate in opposite directions within a casing. As they rotate, the CO_2, or air is drawn into the space between the impeller and the casing. As the impeller continues to turn, it opens to the discharge passage and pushes this volume of trapped gas through the outlet, causing a positive movement of the gases. The two impellers work within a quarter-cycle of each other thereby resulting in a practically steady flow of the gas, with practically negligable pulsation.

Physical arrangement of the system is such as to work naturally with the forces of gravity. An elevated platform (Figs. 3 and 5) supports the dry ice tank with the positive-pressure blower at one side, and the test chamber is at the lowest level. Thus the CO_2 is conducted through a straight short pipe to the test-chamber, while the heated gases rise readily from the test chamber to the pump, from which they are forced into the upper part of the dry ice tank at high velocity.

Dry ice is supported in the tank on a perforated tray mounted at a convenient distance above the bottom. The outlet-pipe projects about six inches above the bottom of the tank. A small baffle plate is located above the outlet to prevent foreign material getting through. The inlet-pipe to the dry ice tank enters tangentially in order to swirl the gases over the area above the carbon dioxide pieces. By this process the sublimation effect is evenly distributed. Any moisture that may enter the system will have a tendency to accumulate on the surfaces of the dry ice in the form of snow. Most of this snow eventually drops to the bottom of the tank, accumulating there along with oil and bits of paper sometimes clinging to the dry ice.

The test chamber *A*, Fig. 2, is arranged to vent to the open atmosphere by being provided with a loose-fitting cover. By this means the greatly expanded carbon dioxide gas is permitted to escape.

The system must be well insulated in order to maintain low temperatures within. The tank was placed upon a pad of cork 8″ thick, painted all over with asphalt. The cork served as a good base for the tank, besides being a good insulator. Alternate wrappings of tarpaper and hairfelt were applied to the tank and over the piping. This was built up to a total thickness of 4″, after which an outer covering of canvas was neatly sewed on. The pump and portions of the valves were left uncovered.

The value of the insulation depends upon the multitudinous air-pockets within the hairfelt or cork. It these should become wet (as by infiltration of atmospheric moisture) the material would no longer serve as an insulator. Therefore, the canvas was given two coats of a good grade of lead-and-oil paint. The asphalt and the tarpaper also serve as vapor barriers.

In making this installation, generous use was made of high-grade flexible rubber tubing, both as a convenient means for making connections to the test chambers, and as a means of preventing transmission of vibration from the pumps to the rigid piping. Vibration dampers were used to isolate the motor and pump bases from the rest of the structure. This is very important not only for the efficiency of the machines, but also for the efficiency of the operators, whose nerves are set at ease by the elimination of vibration and clatter.

The units described have been found satisfactory for the testing of small electronic parts. However, it should be possible to use similar equipment for conducting other types of temperature tests, where it may be required to maintain other characteristics to the time-temperature curve.

Similar equipment could be built for the purpose of maintaining sub-zero temperatures, stabilized at a given point for a certain duration of time. This should meet requirements for metal-shrinking and for low-temperature treatment. These units could also be used as a means for testing organic materials, such as rubbers, plastics and other compounds.

The units are economical to install and use. They are simple to operate. They may be built of simple, rugged components, making maintenance practically negligable. The system provides a reliable and economical means of piping low temperature to the point and place needed.

Fluorescent Street Lighting a Possibility but Filament Lamps Still the Best.—City streets illuminated by brilliant columns of light and glowing fluorescent bars may be a possibility, but according to engineers of the General Electric Illuminating Laboratory, it will be some time before modern cities assume the spectacular appearance of the pseudoscience writer's dream. The present filament lamps are still the most efficient street lighting source in terms of cost and good lighting.

The possibility of fluorescent street lighting is not being overlooked, however, by General Electric engineers, who are constantly working to overcome the difficulties presented by fluorescent lighting, a method which may have the advantage of neater and more attractive appearance.

Fluorescent lamps offer possibilities for many beautiful as well as spectacular effects such as luminous pylons like those employed on world's fair roadways. Moreover, with fluorescent lamps it is possible to produce striking color effects without any loss in lighting efficiency such as occurs when colored "gelatins" are placed around ordinary filament lamps.

In spite of the decorative possibilities offered by fluorescent street lighting, the problems before engineers at present are items of cost per dollar of operation in respect to the amount of visibility obtained and factors of public safety.

Though the installation of fluorescent lighting units upon standards now in use and with existing circuits offers no serious difficulties, the drawbacks of such a system outweigh its advantages. First of all, a fluorescent lamp, unlike the filament type, is highly sensitive to weather conditions. Cold temperatures necessitate jacketing of the lamp to prevent losses in light output.

At present, the principal disadvantages of a fluorescent street lighting system lie in the realms of maintenance and operation, for in many cases light efficiency, glare and visibility have no marked difference over the lamps now in use.

The prime consideration in any new type of lighting is the benefit to be received by the public in terms of visibility obtained per dollar of total lighting cost, regardless of the spectacular appearance which a new unit might present. In this respect fluorescent light, as it has been developed thus far, cannot compete with the filament lamps in use today.

G-E's engineers, however, point to the history of lighting progress as illustrative of new developments in illumination. It was no overnight switch from gaslight to arc light illumination, and many years passed before the present filament lamps came into universal use in street lighting systems. Such is the case with fluorescent lighting.

While the tubes of "cold" light are practical for home and industrial applications at present, the modern city will have to wait for its spectacular fantasy of light until the time when engineers have adapted successfully the fluorescent light to meet the requirements of modern street lighting.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

RAILRAOD TRACK SCALE TESTING.

In spite of limited appropriations and personnel, the Bureau is still rendering an important service to carriers and shippers through its continuous checking of representative railroad weighing facilities. For instance, during the month of September, track scale test car No. 1, in charge of David V. Smith, operating in the States of Washington, Oregon, California, Nevada, Utah, and Colorado, covered more than 2,300 miles and completed one or more tests on each of the following railroads: Northern Pacific; Spokane, Portland, and Seattle; Southern Pacific; Western Pacific; Union Pacific; Nevada Northern; and Denver and Rio Grande Western. During this 30-day period, 20 railroad track scales, including the very important master scales at Portland, Oregon (Public Utilities Commission of Oregon); Oakland, California (Southern Pacific System); and Salt Lake City, Utah (Union Pacific System) were tested. Although only a relatively small number of tests could be made as compared with similar periods when the equipment was operating in the more densely populated eastern States, the amount of work accomplished was very satisfactory. The equipment was able to maintain an admittedly "tight" schedule, involving long hauls and frequent interchanges between carriers.

The equipment is now operating in the Fort Worth-Dallas district where several railroad-owned test-weight cars, that do not have access to any master scale, are being standardized. Recently, three test-weight cars belonging to various railroads were standardized on the Bureau's master track scale at Clearing, Illinois. The facilities of the scale depot were, likewise, utilized in standardizing a 6,100-pound test weight of special design belonging to a large smelting and refining company.

THEODOLITE CIRCLES.

Thorough tests were made of four theodolite circles manufactured by Carl Zeiss in Germany, and brought to this country by I. C. Gardner, chief of the Bureau's Optical Instruments Section. These were found to be excellent circles so far as accuracy of the graduations was concerned. The lines, however, were lacking in quality and did not have the "nicety" of those ruled by B. L. Page of the Length Section. Nevertheless, these were the first foreign circles ever tested at the Bureau that were at all comparable in accuracy with those made here.

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* Communicated by the Director.

IMPACT STRENGTH OF ROPE.

Rope used as safety lines by mountain troops must be strong enough to absorb the impact load resulting from a man falling a distance equal to twice the length of the rope. This worst condition would occur if an individual fell from a position directly above the point of attachment of the rope, with the rope fully extended.

At the request of the Office of the Quartermaster General, nylon and sisal ropes, representing fibers and sizes commonly in use, were tested in order to compare their behavior under static and impact loading. A report, presenting the data in tables and graphs and discussing the results of the tests, has been prepared by Sanford B. Newman and Helen G. Wheeler. It will appear as RP 1679 in the November number of the *Journal of Research*.

Static tests were performed in a hydraulic testing machine; the speed of the head was adjusted to that called for in most specifications for rope. Impact tests were made by using special fixtures that permitted steel disks to fall on a pan attached to the rope.

It was found that the amount of energy absorbed by ropes, up to failure, was greater under impact loading than under static loading. The stretch at or just before failure was the same for both static and impact loading, which is in line with the conclusions of other workers who found the stretch of rope at failure to be the same in static and creep tests.

These tests indicate that it is safe to use the energy determinations derived from static tests for impact purposes if the rope lengths approximate those of the test specimens.

WEARING QUALITY OF EXPERIMENTAL CURRENCY-TYPE PAPERS.

When the supply of linen fiber used to make currency paper was threatened by the war, the Treasury Department requested an investigation of substitutes for the linen fiber and of means for improving the quality of the paper. A considerable number of experimental papers were made of fibers such as linen, cotton, caroa, sisal, and several types of wood. Portions of the papers were surface-sized with glue, which was tanned or hardened with alum or formaldehyde. Some of the papers contained melamine resin which was added to improve the resistance of the surface to abrasion and to increase the strength when wet.

In addition to the usual tests, a crumpling test was developed to simulate the wear of currency in service. The strength, toughness, and wearing quality of these experimental papers indicate that the most promising substitutions or additions, yielding papers comparable to that now used for currency, would be the use of more cotton fiber, the use of some caroa fiber, and the addition of melamine resin. A complete report of the findings has been given to the Treasury Department, and has been approved for publication.

WAR-TIME DEVELOPMENTS IN THE GERMAN TEXTILE INDUSTRY.

The Bureau has agreed to assume responsibility for the operations of the textiles subcommittee of the Technical Industrial Intelligence Committee which was disestablished on September 30. The Bureau will serve as an advisor to the Technical Industrial Branch of the Joint Intelligence Objectives Agency as regards proper completion of the investigation of war-time developments in the German textile industry. About 40 textile technologists are at present employed in this work. The Bureau will be the recipient of the reports prepared by the investigators and the very large amount of material collected by them, and will assume the primary responsibility for the review of such reports and for the analysis and study of the material. The substance of all the information obtained will be made available to the American textile industry through the newly established Office of Information of the Department of Commerce.

ALKALINE WRITING INKS.

Iron gallotannate inks for making permanent records contain high amounts of iron, usually 4 to 7 grams per liter. The formation of sediment is inhibited by acid, frequently mineral acid, which is known to have a deleterious effect on the cellulose of paper. The advantages of a solution, slightly alkaline, of diammonium hydroxyferrigallate, for record purposes, are discussed in *J. Research* NSB 14, 464 (1935). This solution does not appear to be offered by manufacturers. Methods of preparing it and one containing disodium hydroxyferrigallate are presented in an article that W. H. Smith and N. P. Hanna of the Bureau's Chemistry Division have prepared for publication in "American Inkmaker."

STRUCTURAL PROPERTIES OF PREFABRICATED PLYWOOD.

Seventy-five specimens of prefabricated plywood building panels of both light-weight stress-skin and commerical design submitted by the Douglas Fir Plywood Association were tested at the Bureau, and the results are given in Building Materials and Structures Report BMS 104. Wall, partition, floor, and roof constructions were of light-weight stress-skin design. Specimens of commerical type panels were for wall construction only and furnished a basis of comparison of strength and weight with the light-weight constructions. Tests were conducted in accordance with the procedures described in Building Materials and Structures Report BMS 2. Copies of the new report are obtainable from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

COMMERICAL STANDARD FOR DRINKING WATER COOLERS.

The Bureau has just released Commerical Standard CS 127–45, Contained Mechanically Refrigerated Drinking Water Coolers, which provides definitions, general requirements, methods of testing and rating standard rating conditions, recommended normal standard sizes, and minimum capacities, as well as uniform guarantees of ratings of these devices.

The standard applies to all sizes of drinking water coolers, whether of the insulated storage or instanteous types, and whether air-cooled or water-cooled. It includes a list of the elements to be furnished as minimum standard equipment, and provides for the publication of nine items of standard capacity ratings, as well as application ratings for (1) capacity, gallons per hour; (2) storage capacity; (3) ambient temperature; (4) drinking water temperatures, incoming and outgoing; (5) refrigerant used; (6) electrical current used, including kind, voltage, frequency, and phases; (7) power input and/or performance factor; (8) condenser water temperatures, incoming and outgoing; and (9) condenser water consumption of water-cooled condensers.

The standard shoud provide not only a basis for much better understanding between buyers and sellers as to the significance of standard ratings and application ratings, but should also insure fair competition without in any way hampering individual differences of design or construction, or improvements to be developed in the future.

Printed copies of the standard are obtainable from the Superintendent of Documents, Government Printing Office, Washington 25, D.C., at——cents each.

PURITY OF HYDROCARBONS.

In the November number of the *Journal of Research* appears a report (RP 1676) on the determination of the purity of hydrocarbons by measurement of freezing points by Augustus R. Glasgow, Jr., Anton J. Streiff, and Frederick D. Rossini of the Section of Thermochemistry and Hydrocabrons. This report, which was prepared in collaboration with the American Petroleum Institute Research Project 6 on the "Analysis, Purification, and Properties of Hydrocarbons," covers the following topics: Principles involved; apparatus and materials required; experimental procedure for a freezing experiment and for a melting experiment; evaluation of the freezing point from a freezing curve and from a melting curve; calculation of the purity when the freezing point for zero impurity is known; evaluation of the freezing point for zero impurity; and determination of the cryoscopic constant.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, WEDNESDAY, NOVEMBER 21, 1945.

Stated monthly meeting of The Franklin Institute was held at 8:15 on Wednesday, November 21, 1945. Mr. Charles S. Redding, President, was the presiding officer.

After the playing of the National Anthem, Mr. Redding introduced Mr. Paul I. Guest, who spoke on the Victory Loan campaign. In his brief statement Mr. Guest made clear the need for raising funds at this time.

The President then called the meeting to order and announced that the minutes of the October meeting were published in full in the November issue of the JOURNAL OF THE FRANKLIN INSTITUTE, but that, due to an unavoidable delay, that JOURNAL had not yet reached the members; and therefore they would be asked to pass upon the October minutes at the next meeting of the Institute.

He then called upon Dr. John Frazer, Assistant Secretary, in the absence of Dr. Henry Butler Allen, Secretary, who was away because of illness. Dr. Frazer gave the Secretary's report as follows:

New members added since last month:

Active	64
Associate	43
Student	52
	159
Total Membership as of November 1, 1945	5,432

He then called attention to the fact that at the Book Stall at the Institute many interesting books and games were for sale and suggested that members might like to consider them for Christmas gifts for young people.

He indicated also that tickets to the Christmas Week Lectures for Young People would make acceptable gifts.

These lectures, on the James Mapes Dodge Foundation, will be given at 4:30 P.M. on the afternoons of Thursday, Friday and Saturday, December 27, 28, 29, in the Hall of the Institute. A dinner will follow the last lecture. Faber Birren, Industrial Color Consultant and author of numerous books and articles on the effects of color, will lecture on "The World of Color." Tickets may be procured at the Institute.

There was no other business. The President introduced the speaker of the evening, Dr. Ellice McDonald, Director, Biochemical Research Foundation of The Franklin Institute, who gave his annual report on the work of the Foundation. He pointed out that, although the war was ended, certain restrictions still remained on the work of the Laboratories, but his report did cover some very interesting experiments carried on in the application of radiation to physiology and medicine.

After some discussion at the end of the talk, the meeting was dismissed with a rising vote of thanks to Dr. McDonald, at 9:45 P.M.

JOHN FRAZER,
Assistant Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, November 14, 1945.*)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 14, 1945.

MR. JAMES D. LEE, JR., *in the Chair.*

The following report was presented for final action:

No. 3156: Henderson Medal.

This report recommended the award of a George R. Henderson Medal to Tracy Vere Buckwalter, of Massillon, Ohio, "In consideration of his accomplishments in applying anti-friction bearings to railroad locomotives and cars thus contributing to the increase in reliability and decrease in maintenance costs of modern railroad equipment."

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 9 × 14 inches is theirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays from two until ten o'clock P.M.

RECENT ADDITIONS.

AERONAUTICS.

GILBERT, GLEN A. Air Traffic Control. 1945.

AGRICULTURE.

Welsh Journal of Agriculture. Volume 18. 1945.

ASTRONOMY.

SUTHERLAND, LOUIS. The Book of the Stars. 1944.

BIOGRAPHY.

EVANS, HENRY OLIVER. Iron Pioneer: Henry W. Oliver 1840–1904. 1942.

FRANKLIN, BENJAMIN. Benjamin Franklin's Autobiographical Writings, Selected and Edited by Carl Van Doren. 1945.

VAN DOREN, CARL. Viking Portable Library. Carl Van Doren Selected by Himself. 1945.

BIOLOGICAL CHEMISTRY.

HORSFALL, JAMES G. Fungicides and their Action. 1945.

CHEMISTRY AND CHEMICAL TECHNOLOGY.

ALICO, JOHN. Introduction to Magnesium and Its Alloys. 1945.

American Institute of Chemical Engineers. Transactions 1944. Volume 40. 1945.

HUNTRESS, ERNEST HAMLIN. Problems of organic chemistry. First Edition. 1938.

LYNN, ELDIN V. Organic Chemistry. Second Edition. 1945.

MASON, J. PHILIP, AND JOSEPH F. MANNING. The Technology of Plastics and Resins. 1945.

PARRY, J. W. The Spice Handbook. 1945.

ELECTRIC ENGINEERING.

BODE, HENDRIK W. Network Analysis and Feedback Amplifier Design. 1945.
COOKE, NELSON M., AND JOHN MARKUS. Electronics Dictionary. First Edition. 1945.
FRANK, ERNEST. Pulsed Linear Networks. First Edition. 1945.

ENGINEERING.

LEIGH, CHARLES WILBUR, AND JOHN FREDERIC MANGOLD. Practical Mechanics and Strength of Materials. Third Edition. 1940.
RICKARD, T. A. Technical Writing. Third Edition. 1931.
TERZACHI, KARL. Theoretical Soil Mechanics. 1943.

GEOLOGY AND GEODESY.

Annotated Bibliography of Economic Geology. General Index. Volumes 1–10, 1928–1938. 1939.
RAISZ, ERWIN. General Cartography. 1938.

MILITARY SCIENCE.

DIETZ, DAVID. Atomic Energy in the Coming Era. 1945.
MARSHALL, GEORGE CATLETT. General Marshall's Report. The Winning of the War in Europe and the Pacific. No date.
ROBERTS, NED H. The Muzzle-Loading Cap Lock Rifle. Second Edition. 1944.

NAVAL SCIENCE.

CRANE, JOHN, AND JAMES F. KIELEY. United States Naval Academy: the First Hundred Years. 1945.

PHYSICS.

SEELY, FRED B., AND NEWTON E. ENSIGN. Analytical Mechanics for Engineers. Third Edition. 1944.

RAILROADS.

HUBBARD, FREEMAN H. Railroad Avenue. 1945.

SCIENCE.

BAITSELL, GEORGE A., Editor. Science in Progress Second Series. 1945.
LYONS, SIR HENRY. Royal Society 1660–1940. 1944.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

The Effect of Ribonucleinase on Succinic Dehydrogenase and Cytochrome Oxidase.—CHARLES A. ZITTLE. Succinic dehydrogenase has been shown by E. Adler, H. von Euler and B. Skarzynski (*Arkiv für Kemi, Mineralogi och Geologi*, **17A**, No. 2, 1943) to be inhibited by yeast adenylic acid and adenosine, an observation which has been confirmed in this laboratory (C. A. Zittle, to be published). This behavior of succinic dehydrogenase suggested that the finding of V. R. Potter and H. G. Albaum (*Journal of General Physiology*, **26**: 443, 1943) that succinic dehydrogenase and cytochrome oxidase were inhibited by ribonucleinase, although interprepted as indicating a loss of essential structure by the action of the ribonucleinase, might have resulted from the formation of nucleotides in inhibitory amounts by the action of ribonucleinase on the nucleic acid which is present.

The enzymes for the investigation of the above hypothesis were prepared from pig hearts by the method of D. Keilin and E. F. Hartree (*Proceedings of the Royal Society* (*London*), *Series B*, **125**: 171, 1938) except that precipitation at pH 4.5 was not performed. The preparations (six in all were studied) contained about 2 per cent. solid matter and when assayed manometrically with succinic acid as the substrate, after the addition of cytochrome c, 0.16 cc. caused the uptake of about 700 cmm. of O_2 per hour; an uptake of O_2 in the same range was obtained when these preparations were assayed for cytochrome oxidase with hydroquinone as the substrate.

The inhibitory effect of crystalline ribonucleinase (C. A. Zittle and E. H. Reading, *Journal of Biological Chemistry*, **160**: 519, 1945) on these enzymes was confirmed. In several experiments 3.2 mg. of the heart enzymes were treated with 0.16 mg. of ribonucleinase in a total volume of 3.2 cc. for 18 minutes at 37° [the ratio of ribonucleinase to heart enzymes chosen was within the range of 1:200 to 1:6 studied by Potter and Albaum (*op. cit.*) When ribonucleic acid was the substrate for ribonucleinase a ratio of 1:1000 was adequate (M. Kunitz, *Journal of General Physiology*, **24**: 15, 1940)]. Under these conditions cytochrome oxidase and the succinoxidase system lost about 20 per cent. of their activity; with twice as much ribonucleinase a proportionately larger decrease in activity occurred. The succinic dehydrogenase, measured by the methylene blue decolorization technic, with the same time of incubation with ribonucleinase was somewhat less effected.

To determine whether the decrease in activity was due to a release of the inhibitory mononucleotides the enzyme preparation was treated with ribonucleinase and the increase in acid-soluble P (presumably mononucleotides) measured in the following manner. The enzyme was first dialyzed against distilled water to eliminate the phosphate buffer used in its preparation; 5.0 cc. of this preparation were diluted with 10.0 cc. of water and treated with 2.0 cc. (1.6 mg.) of ribonucleinase at 25° for 2 or 18 hours (the results were the same for both times) with chloroform present (in some experiments chloroform was left out with identical results). A control tube was prepared in the same way but with extra water added instead of the ribonucleinase. At the end of 18 hours an equal volume of 10 per cent. trichloracetic acid was added which precipitated the protein and undecomposed nucleic acid (C. A. Zittle and E. H. Reading, *op. cit.*) The precipitates were centrifuged and the P contents of the supernatant fluids determined.

In five experiments with four different lots of enzyme it was regularly found that the supernatant fluid from the control mixture contained on the average 0.024 mg. P per 1.0 cc. of the original enzyme whereas that from the mixture with the ribonucleinase contained 0.038 mg. P per 1.0 cc. of enzyme. Since no P was contributed by the ribonucleinase this must represent a liberation of mononucleotides by the action of the ribonucleinase. It was noted that although the control enzyme remained suspended indefinitely (with increase in age of the preparations there appeared to be a tendency to settle out more rapidly) the treated enzyme settled out much more rapidly, in one instance in less than 30 minutes.

Calculations show that the P solubilized (0.014 mg./1.0 cc.) is approximately equal to 0.028 mg. of nucleotides per 0.2 cc. of enzyme, the amount used in the assays of activity; this amount of nucleotide would equal 1.0×10^{-7} moles. Since 50×10^{-7} moles of mononucleotides are required to give 10 per cent. inhibition of the succinic dehydrogenase (C. A. Zittle, to be published) it is obvious that the inhibition due to ribonucleinase cannot be explained alone on the basis of the mononucleotides liberated.

The total P content of two heart enzyme preparations after dialysis was found to be 0.109 and 0.163 mg. per 1.0 cc. This, if all nucleic acid, would represent an average of 1.36 mg. of nucleotides per 1.0 cc. or 80×10^{-7} moles in a 0.2 cc. sample. This would not account for the level of inhibition observed and it is impossible that all of this P could represent nucleotides, for some must be lipid P and ribonucleic acid is not completely broken down to nucleotides by ribonucleinase (M. Kunitz, *op. cit.;* C. A. Zittle, to be published).

Further study of the inhibition shown by mononucleotides for the succinoxidase system revealed that it does not extend to the cytochrome oxidase (C. A. Zittle, to be published) part of the system, whereas ribonucleinase inhibits both cytochrome oxidase and succinic dehydrogenase (V. R. Potter and H. G. Albaum, *op. cit.*) Accordingly it must be concluded from both sets of experiments that the liberation of mononucleotides does not explain the adverse effect of ribonucleinase on these enzymes.

BOOK REVIEWS.

L'Azeotropie, La Tension De Vapeur Des Malanges De Liquides. Bibliographie. Par Maurice Lecat. 127 pages, 16 × 25 cms., paper. Bruxelles, Maurice Lamertin, Editeur, 1942.

It is now more than twenty-five years since M. Lecat showed the intensity of his interest in azeotrophy by publishing a monograph on the subject, with experimental data and a bibliography—and this is the Belgium of 1918! Since then, the matter has become of increasing importance, and in 1932 the author issued a more extended bibliography, which in the present work is continued to 1942. The number of patents listed indicates the value of the subject in its technical applications, notably in the production of absolute alcohol and in the dehydration of acetic acid. Research workers will be glad to find that the present volume follows the convenient form of that of 1932, the references being printed on one face of the leaf only, leaving the other blank for additional entries, and all interested in the field will undoubtedly find this compilation most helpful.

Emma Ewing.

Television Programming and Production, by Richard Hubbel. 203 pages, illustrations. Murray Hill Books, Inc. 1945. Price $3.00.

The purpose of this book is to provide a foundation for the techniques to television program production. Extensive practical and theoretical experience has been coordinated and evaluated. Many of the conclusions are Mr. Hubbel's personal reactions based on a ten year study of television and conditioned by fifteen years of experience in the established arts of theatre, radio, motion pictures, music, and journalism. It will appeal particularly to those contemplating television as a possible future profession because it not only reviews studio techniques now in use but anticipates advances in equipment and methods of the future.

The author reviews the program of television during the pre-war period and the "behind-the-scenes" advances to early 1945. He compares television with other media of entertainment such as the movies, the theatre, and the radio. Under programming and production, the author discusses fully the camera, Video Technique and Theory, and the Audio. As a conclusion to his book he tells the story of British television.

An unusual feature of the book is the inclusion of more than fifty carefully selected photographs illustrating various types of productions and production problems. These photographs, together with their extensive captions, provide in themselves a highly valuable course of instruction in the tenchnique of television programming. Numerous line drawings vividly illustrate production principles and problems.

D. Collins.

Chemical Engineering Catalog. 1945–46. Thirtieth Annual Edition. 1708 pages, illustrations, 21 × 28 cms. New York, Reinhold Publishing Corporation, 1945.

First issued in 1915, the *Chemical Engineering Catalog* has been for thirty years a primary source of information as to manufacturers of equipment, chemicals and supplies, used in the industries employing chemical processes of manufacture. The familiar arrangement has been kept with the manufacturers' catalogs divided in two sections "Equipment and Supplies" and "Chemicals and Materials" each with its own closely classified index.

Despite the paper shortage the size of the volume has increased over that of the previous edition, although the "Technical and Scientific Books Section" has been curtailed in scope as an emergency measure. With its many varied uses, the chemical engineer will wish to keep the catalog readily available.

George E. Pettengill.

PUBLICATIONS RECEIVED.

Table of Arc Sin X. Prepared by the Mathematical Tables Project conducted under the Sponsorship of the National Bureau of Standards. 121 pages, 19 × 27 cms. New York, Columbia University Press, 1945. Price $3.50.

Physical Chemistry of Cells and Tissues, by Rudolf Rober. 676 pages, illustrations, 16 × 24 cms. Philadelphia, The Blakiston Company, 194. Price $9.00.

Quality Through Statistics, by A. S. Wharton. 60 pages, charts, 14 × 22 cms. London, Philips Lamps Ltd., 1945. Price $1.50 (Paper).

Quality Control Chart Technique when Manufacturing to a Specification, by B. P. Dudding and W. J. Jennett. 74 pages, 14 × 22 cms. Tables. London, The General Electric Co., Ltd., of England, 1945. Price $1.00 (Paper).

Tables of Associated Legendre Functions. Prepared by the Mathematical Tables Project. 303 pages, 19 × 27 cms. New York, Columbia University Press, 1945. Price $5.00.

CURRENT TOPICS.

ARMY AND NAVY NOTES.

Microscopically Fine Glass Fibers Insulate A.A.F.'s Super Troop and Cargo Transport.—A half-inch thick lining of interlaced glass fibers, with an average diameter of five one-hundred-thousandths of an inch, provides heat and sound insulation in the Army Air Forces' Boeing C–97, super troop and cargo transport. The C–97 is a military prototype of the Boeing Stratocruiser, a post-war, double-deck, luxury transport plane which will be capable of carrying 72 to 100 passengers over an operating range of 3,500 miles.

The glass fiber insulation was selected by Boeing engineers on the basis of tests of Fiberglas and other insulating materials, covering thermal and acoustical efficiency, incombustibility, resistance to rot, weight, and moisture pick-up—the last a factor of great importance in aircraft design since moisture absorbed while flying through humid atmosphere increases the dead weight of the plane.

The Fibreglas lining proved to be 225 pounds lighter than alternate installations. During a 16-hour cold test in which the differential vapor pressure across a simulated wall section was maintained at 0.14 inches of Hg, the increase in weight due to condensation of moisture within the Fiberglas was negligible, and weight had returned to normal by the next day. It was concluded that moisture in the insulation should not increase during long periods of operation.

Thermal conductance of the glass fiber lining was 6.3 per cent. less than that of any alternate material tested, and preliminary flight tests showed that the Fiberglas as installed held sound well below the stipulated upper limit for the plane. Because of the natural resilience of the interlaced glass fibers, there was no permanent set, and consequently no bunching or lumping that would necessitate replacement in service. Additional tests demonstrated the lining's incombustibility and freedom from any tendency to rot.

Approximately 7,000 square feet of the Fiberglas lining, with a total weight of 182 pounds, are installed in the C–97. The lining is formed by bonding the fibers with a thermo-setting resin, and covering the interlaced mass of fibers with an incombustible fabric.

R. H. O.

Glass Armor Worn by Amphibious Forces.—A modernized version of the medieval coat of mail, but with glass taking the place of steel, is being worn by U. S. Naval amphibious forces, the Navy Department disclosed recently.

The modernized coat of mail consists of kapok life preservers, or various types of jackets, which have been modified to provide pockets for the insertion of sheets of armor of various shapes and sizes. This armor, thin, tough sheets of glass fiber cloth impregnated and bonded with resin, is inserted in the pockets. The glass-resin sheets have extraordinarily high impact strength, are light in weight, and, unlike metal, will not rust or corrode in humid climates.

The armor will not stop a direct hit, but it will give the wearer protection against shell splinters and other flying bits of metal that are responsible for a large number of casualties.

R. H. O.

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